The Quantum World and the Dancing Specks of Sentience

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ABSTRACT

This paper focuses on practical issues regarding the quantum world, in a bid to unpack the inner logic of Nature. It analyses a few landmark experiments that raise tough conceptual challenges—yet do make good sense if we assume that quantum randomness is more than a sheer lack of determinism. Intriguingly, this assumption sheds new light on some of the conscious brain's deepest secrets. It also suggests fresh insights as regards the meaning of life and our place in the universe.

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Bare bones to chew on

J.B.S. Haldane famously said that "*Nature is not only stranger than we think, it is stranger than we* can *think*." The quantum world proved him right! It is notoriously strange, with its atoms and particles that seem able to be in more than one place at once, or to spin clockwise and anticlockwise at the same time. They also display randomness. They behave as highly localized particles when we watch them and as spread-out waves when we don't. When atoms and particles evolve as waves, they typically "wiggle" as combinations or superpositions of two or several simple states, each having some clear-cut properties. These superpositions or mixtures of simple states are blurred. They lack definite properties. When observed, quantum systems like electrons, atoms, and photons are said to collapse. They dramatically change their behaviour and pick up definite properties. No one really knows why.

Quantum systems, say a pair of photons, can also be entangled. When they are, measuring a property of one may instantly influence a property of the other, regardless of their distance. This means that one photon that collapses, maybe upon being measured or observed, will *instantly* influence its entangled twin, however far apart it is. This is odd, and quite unexpected in a universe where velocities cannot be greater than the speed of light in the vacuum—so that no event, be it an act of observation, should ever wield an immediate influence at a distance. Playwright Tom Stoppard thus describes the quirks and feats of quantum particles:

> The particle world is the dream world of the intelligence officer. An electron can be here or there at the same moment. You can choose. It can go from here to there without going in between; it can pass through two doors at the same time, or from one door to another by a path which is there for all to see, until someone looks, and then the act of looking has made it take a different

path. Its movements cannot be anticipated, because [they have] no reasons. It defeats surveillance because when you know what it is doing you can't be certain where it is, and when you know where it is you can't be certain what it's doing: Heisenberg's uncertainty principle; and this is not because you're not looking carefully enough, it is because there is no such a thing as an electron with a definite position and definite momentum; you fix one, you lose the other, and it's all done without tricks, it's the real world, it is awake[1].

These facts and properties are so strange that many share this opinion of Jim Al-Khalili: "*If we have learnt anything about quantum mechanics, it is that searching for rational explanations is a futile exercise*."[2] However, I beg to differ. I believe that quantum weirdness, like beauty, is in the eye of the beholder and nowhere else. It would be due to a failure to grasp the inner logic of Nature[3]. On this insight, I put forward a conceptual approach whose bare bones are:

(1) Left to their own devices, electrons and the like move forward as bunches of waves called wave packets or wavefunctions[4]. These quantum waves interfere only within their own wave packet or wavefunction, which *either* forms simple and "unique" states like those of ordinary cats and objects, with maybe a well localized position or a sharp and well-defined momentum, or a precise energy. I call them **sharp** states. *Or else*, they form states that combine or superpose several simple states. These "multiple" states have fuzzy values of some attribute, such as their position or energy. I call them **fuzzy** states.

(2) Circumstances exist where the wave packet or wavefunction associated, say, to an electron is under threat of being split into subunits that can no longer interfere mutually. I call these circumstances, sometimes created by a detector in an act of measurement, ***quantum threats***. They can only arise if the electron is in a fuzzy state, whose splitting into non-interfering bits is ruled out by what I call the ***quantumhood principle***[5].

(3) To ward off a quantum threat, an electron jumps or collapses. This game-changing event is swift, waveless, and random. It shrinks the electron's fuzzy state, which is threatened, to a threat-free sharp state. Indeed, **the collapse is Nature's way to cope with quantum threats and shun contradiction**. It is a fuzziness-buster and a sharpness-maker[6].

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[1] This passage of Stoppard's play 'Hapgood' is from Jeremy Bernstein's book *Quantum Leaps* (The Belknap Press of Harvard Univ. Press, 2009).

[2] Jim Al-Khalili, *Quantum. A Guide for the Perplexed*, Phoenix, 2003.

[3] It reminds me of this question asked by Peter Gribbins in his book *Particles and Paradoxes* (Cambridge University Press, 1989): "*Could it be that the paradoxes of quantum mechanics are no such thing and are merely the side-effects of using the wrong logic?*"

[4] Wave packets and wavefunctions are made of mutually interfering quantum waves. Their amplitude is given by a complex number which yields a real number norm when squared. Waves interfere, here constructively and there destructively, when their crests and troughs overlap—like the ripples left by stones thrown in water. Quantum waves are widely held to be abstract and nonphysical "waves of probability," as Max Born suggested in 1926. However, I don't buy into this probabilistic interpretation, which doesn't depend on velocities *but* demonstrably fails for photons and ultrafast or "ultra-relativist" particles (it is because velocities can't be greater than that of light in a vacuum). Ironically though, in the two-slit experiment that I'll present, the photon is often used to introduce and justify the probability interpretation of quantum waves! Indeed, the probability wave idea *only* makes sense when a quantum system undergoes a collapse (soon to be defined)—for which we can only compute the likelihood of obtaining this or that outcome, by squaring the wave amplitude. It is quite unclear, too, why purely abstract wavefunctions should never propagate faster than light—why should they always appear to respect the very concrete relativistic speed limit (that of light) that rules physical motions? This barely squares with their alleged nonphysical nature. Moreover, several experiments suggest that the wavefunction is not a purely abstract entity lacking any shred of physical reality. An experiment carried out by Alessandro Fedrizzi *et al*. in 2014, using polarised photons, is one of them. Its results suggest that "*if there is any objective description of the world, the wave function is part of it*." Another example is an experiment made in 2016 by Bertúlio de Lima Bernardo *et al*., using something called the "entanglement mediation protocol" (see 'How a single particle simultaneously modifies the physical reality of two distant others: a quantum nonlocality and weak value study', DOI: 10.1038/srep39767, 2017).

[5] I take ***quantumhood*** to mean "wave wholeness" with respect to the entirety or integrity of a wave packet associated to an elementary particle. It is defined with respect to wave interference, and not to space. It rests on the ability of quantum waves to interfere within a wave packet. Then, the *quantumhood principle* is an "all-or-nothing" rule whereby no particle evolving in its wave-like fashion (i.e. without collapse) will split into bits that could no longer interfere mutually—this would go against *quantumhood* and—this is the catch—make Nature inconsistent. Mathematically speaking, this principle translates into the fact that (a) the integral of the wave packet or wavefunction over the whole of space can always be normed to unity (in symbolic language: $1 = \int_{\text{all of space}} |\Psi\rangle|\Psi\rangle d^3x = 1$, $|\Psi\rangle$ being the *ket* of the wavefunction), and (b) the time evolution of the wavefunction (without collapse) is unitary (***unitarity*** is a mathematical property which preserves the value of the scalar product between states). Incidentally, the principle of quantumhood implies the quantization of matter at the microscopic scale. Note that "when the electron is in a fuzzy state" and "when the electron is fuzzy" are shorthand ways to say: "when the wave packet or wavefunction associated to the electron is in a fuzzy state".

[6] The collapse, or jump, is a waveless and random transition. It is also an a-relativistic (or "non-covariant relativist") event. (More in my paper 'Making Sense of Quantum Randomness', at: https://www.galileocommission.org/can-we-crack-the-mind-body-problem-part-i-emmanuel-ransford.) Oddly enough, the quantum rules for computing the probability of occurrence of a (collapse-driven) sharp state are not those of the classical probability calculus. The reason is that *distinguishable* and non-interfering paths leading to different sharp states relate to alternative events while *indistinguishable* paths within a fuzzy state belong to the same event (we'll soon see what this means precisely). In the first case, the probabilities (obtained by squaring the wave amplitudes) are added up, in keeping with the common-sense rules of the classical calculus. In the second case, we don't sum up the probabilities of single paths since here we are not dealing with distinct and independent events. Instead, the (complex-number) wave amplitudes linked to the indistinguishable paths must first be summed up on account of their mutual interference. Only then the likelihoods of the sharp states that will randomly arise in the event of a collapse can be computed, using the same *classical* probability calculus as with sharp states.

(4) In a fuzzy state, there is always a physical attribute that has an ill-defined value and hence doesn't exist in a conventional way. This raises a conundrum when two 'fuzzy' quantum objects—e.g. two electrons—are linked by a shared conservation law where the conserved attribute has an ill-defined value. Then, this law or shared constraint is only *virtual* because it can't be made effective and actual. I call such a constraint a ***supra-conservation law***. Quantum systems linked by it are said to be ***entangled***[7].

(5) Nature manages to keep track of a supra-conservation constraint, or law, when it is virtual. In our example, it does so by *entangling* the two electrons in a nonlocal way or rather, in a *distance-blind* way. Therefore, the sharp states necessary to actualize the law will arise simultaneously, in the same distance-blind way, no matter how far apart the two electrons are.

(6) In short, **quantum entanglement is Nature's way to keep track of supra-conservation laws when they are still virtual**. It is an amazing trick whereby Nature manages to remain consistent in the face of the daunting challenge of supra-conservation constraints. Two sources of entanglement are currenty known, one due to supra-conservation laws and the other linked to quantum indistinguishability[8].

(7) It takes a collapse to actualize a supra-conservation law. Let's see why. This event is shared instantly by, say, the two entangled electrons. It is triggered by a quantum threat, perhaps due to a detector in an act of measurement foisted on an electron of the pair. The collapse shrinks the collective and fuzzy two-electron wavefunction that is threatened and brings it to a threat-free sharp state[9] where the conserved attribute becomes definite. Now this attribute has clear-cut values for both electrons. Accordingly, the supra-conservation law is no longer virtual. It becomes actual and *correlates* these values.

(8) When, in our example, the supra-conservation law becomes actual and tangible because a collapse shrunk the two electrons into correlated sharp states, their bond of entanglement becomes useless and redundant since the shared constraint gave the duly correlated outcomes and no longer needs to be kept track of. So this bond, which I also dub a *supral link*, dies off. It is severed. I say that the collapse is ***supralicide***, because of its ability to cut off supral links[10].

(9) To recap, the mind-bending features of the quantum world—namely, the collapse and entanglement—serve the all-important purpose to steer Nature clear of contradictions that would otherwise crop up. This spells out the reason behind the collapse and the measurement problem, behind entanglement and nonlocality too.

These "bare bones" give a broad outline of my approach[11]. It sees the collapse, for which no dynamical description has been found, as a real process whose role is to nip quantum threats in the bud. This collapse interpretation of quantum physics rests on these three basic ideas: (a) quantum waves are waves of substance or "stuff-waves" whose mutual interference can wreck Nature's consistency[12]; (b) lest they do so, they sometimes must be put on hold; (c) this is done through the ***quantumhood principle***. This

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[7] Often, after a collapse, the resulting sharp state is absorbed and destroyed. An example of shared conservation law is given by the 'singlet' spin state of two electrons, in which the values of their spins add up to nought with respect to any arbitrary direction, without each spin having a preordained value. Sometimes I say, half in jest, that quantum waves are prone to be involved in kith-and-kin relationships. ***Kin-waves*** are associated to an elementary particle, that is, they belong to the same wave packet (barring any entanglement). ***Kith-waves*** belong to the wavefunction of a broader entangled whole—they belong to the same global (multi-particle) wavefunction. (*Kith* derives from an old English word referring to a cohesive group sharing common customs and beliefs.) Then, we can say that there's a kill-switch for *kin-waves*. It is turned on when a waveless event happens—i.e., when a collapse happens. There's a kill-switch for *kith-waves* too. This one is turned on when a supra-conservation law becomes actual, which is due to a *shared* collapse. Both kill-switches are tightly linked to quantum wave collapses (which, accordingly, I'll soon say are *supralicide*).

[8] These two kinds of entanglement protect or shield Nature's consistency, exactly as a collapse does when a quantum threat looms large. I call them ***entanglement-by-supra-conservation*** and ***entanglement-by-indistt***. More in my Galileo Commission paper 'Matter and the Poached Egg' (https://www.galileocommission.org/can-we-crack-the-mind-body-problem-part-ii-emmanuel-ransford/?swcfpc=1).

[9] For an entangled and hence a composite system, the local sharp states of the subsystems (to wit, of each electron of the pair) are individually defined by "tracing out" the entangled partners (this is a mathematical technique of algebra consisting of taking a partial trace).

[10] In my (holomatter-based) approach, I call a bond of entanglement a *supral link* because the property of entanglement results from the property of ***supralness***, also called 'in-binding' since it relates to in-causation. It is distance-blind and creates non-local correlations. (More, again, in 'Matter and the Poached Egg'.) Note that when a *supralicide* collapse cuts off a bond of entanglement, each disentangled partner gets a wavefunction of its own.

[11] Furthermore, as we'll later see, this approach looks set to bring fresh ideas and insights to bear on the riddle of the conscious brain.

[12] Unlike ordinary waves that are 'stir-waves' or motion waves and need a medium in which to exist and propagate (e. g., waves in water, sound waves in the air…), these 'stuff-waves' or waves of substance don't depend on a preexisting medium and can spread in a vacuum. As such, they reach deep into the roots of reality. Quantum waves being stuff-waves, they are a core element of its ontological fabric. It means that what lurks at the deepest level of reality isn't something solid and static, but events—*self-begetting* events. (See my paper 'Making Sense of Quantum Randomness', already cited. Also see my books in French, *L'Univers Quantique enfin expliqué* and *Huit Leçons essentielles sur la science quantique*.) Interestingly, in his best-seller *The Tao of Physics*, Fritjof Capra observes that "*Relativity theory […] has shown that the activity of matter is the very essence of its being. The particles of the subatomic world are not only active in the sense of moving around very fast; they themselves are processes! The existence of matter and its activity cannot be separated. They are but different aspect of the same space-time reality*." He then asks: "*If the particles themselves are processes, what kind of process are they?*" My short answer is that these processes are ***self-begetting*** processes, whereby particles "bootstrap" themselves into being. Note that quantum waves are solutions to a wave equation (usually the non-relativistic Schrödinger equation) which is linear, so that a combination or superposition of its solutions is also a solution. This is why fuzzy (or superposed) states do exist. Also, quantum waves, as a rule, interfere within their own wave packet only. They may challenge Nature's consistency, since wave interference is not a zero-sum game.

principle is the unsung hero of the quantum world and pulls its strings, to help Nature remain contradiction-free. Indeed, in the absence of the quantumhood principle, there would be no quantum threat. There would be no collapse and no entanglement either, and hence no quantum randomness and no non-locality. This would remove two major stumbling blocks on the way to quantum gravity. The physical world would roughly be as described by classical physics. Alas, shorn of the quantumhood principle, Nature would be in the throes of contradicton[13]. Therefore, Nature can't afford to let go of it and must remain weird and quantum at heart!

Eerie measurement, spooky entanglement

From the "bare bones" we gather that:

- The collapse of a quantum system is a shrinking, waveless, and random event. Before its onset, the various sharp components of the fuzzy state are *indistinguishable* or *coherent*, which means that they are intertwined—they can and do interfere mutually. After the event, these components become *distinguishable* or *decoherent*, which means that the quantum system has evolved into a single sharp or narrow component. Then, no other component remains, that would still interfere with it. In short, **the fuzziness of quantum states means mutual interference and lack of distinguishability; the sharpness of quantum states means distinguishability and lack of mutual interference**[14].
- A measuring device has two main parts, which are its analyser and its detector. The ***analyser***—e.g., a beam-splitter—puts the measured system in a fuzzy state as regards a specific attribute (position, spin, energy...) chosen by the experimenter[15]. The ***detector***—e.g., a photosensitive screen—uses this fuzziness to generate a quantum threat that will soon trigger a collapse which, in turn, will shift the system from its fuzzy state to a threat-free sharp state. This collapse-driven sharp state is always picked out of the many sharp components contained in the earlier fuzzy state. Accordingly, it is unique and random. It brings out a unique and definite measurement outcome as regards the targeted attribute.

After going through the analyser, a photon being measured is fuzzy but whole, in the sense of *quantumhood*[16]. This holds true even when an analyser, maybe a half-silvered mirror or a beam splitter, makes the photon spawn two half-photons flying in differing directions. These half-photons put the incoming photon in a fuzzy state. They do not stand on their own, but keep interfering mutually, whether near or far or hugely far, owing to their overlapping tails. Granted, these tails are exceedingly dim—nigh on inexistent! They belong to the respective and virtually boundless waves of the half-photons, and they interfere[17]. If we forget this detail and forget that a collapse is distance-blind, we may fall into the trap of believing that backwards in time events occur when a fuzzy state collapses into a sharp one in a delayed choice setting. Soon we'll see that with delayed choice experiments.

Now suppose one of the half-photons hits a detector. It will react to the resulting quantum threat but really, it is the fuzzy photon *as a whole* that will react, by collapsing *as a whole*. It will shift from its fuzzy state to a sharp one that will collapse the two half-photons *simultaneously*. One sharp state will be selected out of all those possible, each corresponding to a half-photon. Now, if the resulting sharp photon matches the half-photons hitting the detector, it will be detected. Perhaps it will be absorbed forthwith, and recorded. This is how a quantum measurement is generally understood. We'll say that this sharp state is ***factual***. Contrariwise, if the collapse shrinks the photon towards the other half-photon, it won't be detected since no detector is there. It will be unseen and unacknowledged. We'll say that this sharp state is ***counterfactual***. In this case, it seems that a measurement free collapse or an interaction-free event took place, and this lack of detection is often misinterpreted as rock-solid proof that no collapse happened.

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[13] The contradiction, as I already suggested, is due to the interference of quantum waves, which is potentially harmful because they are "stuff-waves" and not "stir-waves". Again, this is justified in the GC paper 'Making Sense of Quantum Randomness'.

[14] In the two-slit experiment as we'll see, sharpness (and hence distinguishability) begets which-slit or which-path information. Fuzziness (and indistinguishability) doesn't yield information, insofar as the (fuzzy) both-slit information is often treated as no information at all. Note that which-slit information (or which-arm information if an interferometer is used) is often called particle-like information. This is inaccurate and misleading and may feed a common fallacy that some textbooks articulate by stating that 'waves' go with 'mutual coherence' but 'particles' go with 'path indistinguishability'. Particles and path indistinguishability actually refer to sharp states, just as quantum waves and mutual coherence go with fuzzy states. Recall that both a sharp state and a fuzzy state of a wave function are equally wave-like and "real", or "actual".

[15] This dependence on the analyser is confirmed by the Kochen-Specker theorem, which establishes that a measurement outcome is *contextual*, so that no clear-cut measurement value exists before being created by the measuring apparatus (and really, by the fuzziness-busting collapse involved). Here, a quantum system is made to evolve to a certain type of fuzzy state, and then to a random sharp state, *because* of the analyser-cum-detector measuring apparatus. The choice of the analyser is made by the experimenter. It determines what type the fuzzy state will be in.

[16] Recall that *quantumhood* is wholeness defined with respect to wave interference. It holds as long as the wave packet associated to a particle, say, isn't broken or split into sub-packets now unable to interfere mutually. The ***quantumhood principle*** sees to it that *quantumhood* is upheld whenever particles evolve in their wave-like fashion. Because of this principle, we can't find independent bits of particles (e.g., true half-photons or one-third of protons or quarks...).

[17] This is consistent with the fact that the concept of *quantumhood* is interferential and not spatial. Of course, here the word "half-photon" is a misnomer since, strictly speaking, we are dealing with a photon which happens to be fuzzy in a spectacular way *but is still whole*. I hope that this won't create a confusion. Note that quantum threats target fuzzy states, not sharp ones, because the smeared-out character of fuzzy states makes them easy to "pinch" and break. Sharp states, on the other hand, are typically threat-free. It is why a collapse is a fuzziness-buster and a sharpness-maker....

But make no mistake: it isn't so. In *both* the factual and the counterfactual cases, a detector-prompted collapse occurred—only with a different sharp outcome, detected or not. The Elitzur-Vaidman bomb test will illustrate this counterfactual fallacy.

Two additional remarks are in order:

- Collapses may occur without an act of measurement involving a macroscopic measuring device. Some collapses are triggered by disturbances and collisions. Or by quantum instability, which elicits spontaneous decays[18].
- Fuzzy and sharp states are *always* and *equally* wave-like. This can't be overstressed! No fuzzy quantum state can ever be a mixture, or a superposition, of a wave and a (point) particle[19].

That the wave-particle duality is really a wave-collapse duality and hence a fuzziness-sharpness duality is well illustrated by the two-slit experiment. For its detailed description, see on the internet and in articles and books about quantum physics. It was first carried out in 1801 by Thomas Young, a British physician and gifted polymath who wanted to show—against Newton—that light is a wave phenomenon. According to Peter Gribbins, this experiment *"presents wave-particle duality in a particularly stark form [and] brings out the fact that how the phenomenon appears to us, whether we say that the photon goes through both or only one of the beams, depends on decisions we make*.[20]" It involves shining a beam of light through two parallel and narrow slits cut into a thin metallic sheet, which plays the role of the analyser of a measurement apparatus. In its modern version, the experiment involves firing photons[21] *one at a time*, let's say from the left. Then, farther to the right, a screen detects light after its passage through the slits.

Running the experiment, we find that every photon absorbed on the screen leaves a tiny dot here or there on its surface. This random dot is often seen as a robust and compelling proof that a photon that waves its way forward can also be a discrete point particle—this is wave-particle duality caught in the act! Now, if we wait long enough so that there is a buildup of these dots, an interference pattern comes into view. This pattern, made up of several bright and dark stripes parallel to the slits, shows that light is also a wave phenomenon. The explanation goes as follows. When the waves ascribed to an individual photon pass through both slits at the same time[22], their overlapping wavefronts diffract and interfere, here constructively and there destructively. If light were made of classical point particles, we would see two bright stripes only, one for each slit. Instead, as explained by Jim Al-Khalili, "*the separate light waves emerging from the two slits spread out, overlap and merge before hitting the back screen. Where two wave crests (or troughs) meet they combine together to form a higher crest (or lower trough) that corresponds to more intense light and hence a bright [stripe] on the screen. But where a crest of one wave corresponds to the trough of the other, they cancel out resulting in a dark patch. In between these two extremes some light survives and there is a gradual blending in of the pattern on the screen*[23]."

So far so good. But how can a photon, if it is a point particle as we may think, pass through the two distant slits at once? This seems flat-out impossible; but the interference pattern suggests otherwise, so we need to check. To that end, we place a spying device right behind the slits. It will keep track of each photon's path as it goes through the sheet. Running the experiment with the spying device switched on, we find that each and every photon goes through one slit only. This is intuitively satisfying and comes as a relief: the photon, as expected, behaves as a tiny particle. However, this relief is short-lived, since we soon discover that the interference pattern is gone. Turning the spying device on wipes it out—so we're still in the dark about the path of each photon that contributes to the interference buildup. What we found, oddly enough, is that *either* we know how the photon crossed the two-slit sheet, *or* we have the interference pattern, and never both together.

Why do photons behave as point particles when watched or detected, and as waves otherwise? We'd like to know. My answer is that the sharp state of a fuzzy photon (i.e., a photon in a fuzzy state) arises, as it strikes the screen, *because* if it were to keep its waving motion throughout, this photon would be absorbed by bits since its waves are spread out over the screen surface. Such an evolution goes against the principle of quantumhood and is a no-go. To avoid it, a collapse is in order. It shrinks the photon to a pin-sharp position on the screen, which is then absorbed whole, as required by the principle of quantumhood. It is how the collapsed

18 Unstable systems can somehow be seen as having a microscopic "inner detector" linked to their fuzzy energy. Sooner or later, they collapse or decay. The average duration of their unstable state can be calculated from the time-energy uncertainty relation.

19 In the symbolic language of physics, this fallacy can be expressed by the formula: $(|\Psi\rangle = \sqrt{½}[|BS_{present}\rangle|wave\rangle + |BS_{absent}\rangle|particle\rangle]$ (BS stands for beam splitter, a more elaborate equivalent of a half-silvered mirror). Some use it to "explain" delayed-choice experiments. Note in passing that the quantum world has two alternative evolution laws only. One is unitary, deterministic, and wave-like. The other is non-unitary, random and "collapse-like". There's no other possibility, so that if an evolution, event, or transition is found to be non-unitary, we can safely infer that it is a collapse.

20 Peter Gribbins, *Particles and Paradoxes*, Cambridge University Press, 1989. "The decision we make" is about our choice of the analyser, which in turn defines the fuzzy state out of which the final sharp state will be randomly selected.

21 The photons used are always monochromatic, or single-coloured (they have the same wavelength). The two-slit experiment has also been performed with electrons and atoms, with essentially same the result.

22 This is an instance of fuzzy (*aka* superposed) state, made up of two sharp states, each corresponding to the photon passing through a single slit, either one or the other.

23 Jim Al-Khalili, *Quantum. A Guide for the Perplexed*, Phoenix, 2003.

photon leaves a highly localized dot on the screen. Clearly, this dot isn't the mark left by a point particle. It is the footprint of a random and highly localised sharp state.

The spying device is another detector. When turned on, it elicits a collapse which produces a one-slit or which-slit sharp state randomly chosen, so that the selected slit can't be known beforehand. No foreknowledge of the which-slit or which-path information can be had[24]. Of course, this which-slit state yields no interference pattern, for want of an "interfering partner" that would go through the other slit.

To recap, both the screen and the spying device generate quantum threats since both are detectors. Therefore, in the two-slit experiment, **an incoming photon undergoes *one* collapse when the spying device is off and *two* collapses when the spying device is on**. The first collapse happens near the slits when the spying device is on. It shrinks the photon's wavefunction to a random one-slit sharp state responsible for the later lack of interference on the screen since the photon now behaves as if the other slit were shut. It yields which-slit information. Contrariwise, when the device is switched off, the photon remains in its two-slit fuzzy state and contributes to the interference pattern. The second collapse—which is the only one when the device is off—is due to the screen. It leaves a random dot on its surface as we know. I contend that the two-slit experiment is no trickier and no weirder than that.

In all this, we deal exclusively with wavefunctions and collapses, and we recall from the "bare bones" that the wave-particle duality is really a wave-collapse, and hence a fuzziness-sharpness, duality. Fuzzy and sharp states alike refer to wavefunctions, not to discrete point particles. **The two-slit experiment involves nothing but threatened fuzzy states, collapses, and threat-free sharp states**. It is why "*If no "which-path" information is available we have interference, whereas if "which-path" is available there is no interference. […] it is enough just for the information to be* potentially *known even if the observer does not do anything to obtain that information*[25]." Lest we misinterpret this citation however, let me stress that human knowledge, potential or otherwise, is irrelevant. It plays no causal part here, being a mere *consequence* of perceiving what goes on. When a state is fuzzy, interference and both-path information result *because* of the both-path fuzziness. When a state is sharp, no interference results and which-path information is available *because* of the one-path or which-path sharpness. Of course, a both-path state arises when the spying device is off and a which-path state is found when the device is turned on. It is worth stressing time and again (to counter a widespread fallacy) that which-slit information is created when the spying device is on *because* it is prompted by a collapse that shrunk the earlier both-slit fuzzy state to a which-slit sharp state. When this information isn't available, it is *because* the photon remained in a both-slit fuzzy state—the spying device being off.

Clearly, **the availability of which-slit or which-path information is not the cause of the loss of interference but the *consequence* of the sharp state**. When both slits are open, saying that which-slit information is available is just a way of saying that the photon flew through them in a collapse-driven sharp state. This sharp state isn't a mere information update in the mind of the observer.

Nowadays, experimenters use Mach-Zehnder interferometers rather than two slits. These MZI have two arms made with two mirrors and two beam splitters. Two detectors are added, so that "*Light entering the interferometer hits a beam splitter, which sends the light along two optical paths: an upper and a lower one. The paths recombine at the second beam splitter, which sends the light to one of two photon detectors. Thus, the interferometer gives each photon two possible paths between the light source and a detector*."[26] These arms can be far apart. A photon flying through travels along both routes at once as its wavefunction is in a superposition of two bits, each travelling in a different arm[27]. One may then say that quantum particles can be in superpositions of two or more places at once. Yet if a fuzzy photon (i.e., a photon in a fuzzy state) hits a detector in one arm, its wavefunction will shrink to a sharp which-arm state. It will appear to behave like a very localized particle, and some will claim that "*the whole spread-out wavefunction collapses into a single real particle in one arm or the other when we look*". "*When we look*" is a loose and shorthand

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[24] Accordingly, the theory never predicts which sharp state will be picked out of the 'multiple' fuzzy state. It can only work out the likelihood that this or that potential sharp state—always contained in the 'multiple' fuzzy state—will become actual if a collapse strikes. Fuzzy particles may spin in two directions at once, or combine two or more speeds or energies (different energy levels characterise unstable quantum systems). Note that because a wave can traverse the sheet thought both slits at once while a point particle can only go through one slit at a time, the which-slit (or which-path) information is often called a particle-like information whilst the both-slit (or both-path) information is called a wave-like information. These however really mean sharp-state information and fuzzy-state information respectively.

[25] From *The Quantum Divide*, by Christopher C. Gerry and Kimberly M. Bruno, Oxford Univ. Press, 2013. That it is enough for the information to be *potentially* known really means that it is enough for the which-slit information to *exist* objectively (it does so after a sharpness-yielding collapse).

[26] Excerpt from the article 'Quantum Seeing in the Dark', by P. Kwiat, H. Weinfurter and A. Zeilinger (*Scientific American*, November 1996).

[27] These two bits are still interfering mutually through their remotely overlapping tails, so that the photon remains an interfering whole—as required by the quantumhood principle—despite its spatial dispersal. Jim Al-Khalili comments: "*[The] two arms of the interferometer can be arbitrarily far apart—in practice they can be several metres apart. This makes it particularly difficult for us to envisage the photon just as a wave. Its wavefunction really seems to now be in two isolated places*." (Jim Al-Khalili, *Quantum. A Guide for the Perplexed*, Phoenix, 2003. However, these two bits or "sub-wavefunctions" that seem to be "*in two isolated places*" have vanishingly faint overlapping tails that keep interfering mutually. The overall wavefunction is widely spread-out spatially *but is still whole*. Al-Khalili explains that "*Interferometers are devices that highlight the way a single particle can travel along two paths at once and, once brought back together again, give rise to an interference pattern or some other type of signal that provides proof that something must have travelled along both routes*." (*op. cit*.)

way to say: "*When we use a measuring device whose detector creates a quantum threat that triggers a collapse driving the photon into a random sharp state.*" Of course, instead of a photon we could take any quantum system, e.g. an electron or an atom.

My take-home message is this: **we need four basic concepts to come to grips with the quantum world. These are fuzzy states, quantum threats, collapses and sharp states**[28]. These concepts are in a dynamic interplay, and ***when a photon in a fuzzy state is under a quantum threat because its environment—e.g. a detector—would break its wavefunction into non-interfering bits, it will respond by collapsing into a sharp and unthreatened state where the risk of breaking is gone***. Quantum threats feed on fuzziness. It is why a measurement apparatus contains an analyser whose role is to produce fuzzy states before the detector comes into play.

Finally, I briefly mention two thought-provoking experiments which starkly raise the issue of time and causation in the quantum world (I only mention them because I'll analyse them in another article). The first is the ***quantum switch***. This switch allegedly yield an indefinite (or fuzzy) causal order and so appears to challenge the conventional notion of causation[29]. The second is the ***"time-slit" experiment*** performed in 2023 by Riccardo Sapienza at the Imperial College of London. These "slits" are separated in time instead of being separated in space. The interference effects involve frequencies, not wavelengths as in usual the two-slit experiment. A peculiar property of an optical material, indium tin oxide to name it, made it possible.

What about quantum entanglement, now? This bizarre property is about instant and non-local correlations between chunks of matter. We learn that "*Particles can become entangled when they interact, and once they do, no matter how far apart they are, measuring the properties of one automatically fixes the properties of the other*." Or else, "*When two electrons, say, are brought together in a certain way and then separated, measurement on one instantaneously seem to influence the outcome of measurements on the other—even though there is no conceivable way the pair could communicate*." It is as if two entangled particles separated by any distance nevertheless manage to share information. Is this quantum magic? Entanglement implies that if you measure a particle here and now you instantly modify another particle entangled to it, even if this other particle is zillion miles away. Well, it seems that entanglement doesn't fit any better, in our relativistic universe where nothing can travel faster than light, than square pegs in round holes.[30] Perhaps the entangled partner somehow 'knows' immediately that you performed your measurement zillion miles from it? Or perhaps some back-in-time effect is at work?

These are awkward and daunting questions. This, however, is not woo-woo science: some technologies are built around entanglement, e.g. quantum computing and cryptography. Entanglement is also an interesting resource in some experiments because it makes it possible to learn something about a particle without disturbing it, through another particle entangled to it. David Mermin points out that "*The mystery of [entanglement] is that it presents us with a set of correlations for which there simply is no explanation. The majority would probably deny even this, maintaining that the quantum theory does offer an explanation. That explanation, however, is nothing more than a recipe for how to compute what the correlations are*[31]." Familiarity breeds a false sense of understanding.

However, I am convinced that the existence of entanglement can be explained, in that it serves a purpose. The "bare bones" hinted at such an explanation, which goes as follows: "*Entangled particles separated by any distance conspire to uphold nature's consistency*[32]." Let me add four remarks:

(a) A bond of entanglement can be seen as *distance-blind* because it is instantaneous and doesn't fall off with the distance.
(b) This bond cannot be used to send out an information-bearing signal instantly, and hence faster than light. This is ascertained by a theorem[33].

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28 Note that quantum waves are present through fuzzy and sharp states, but the point particle isn't in this list. Or course a fifth concept, that of quantum entanglement, must be added to complete the list.

29 See at 10.1103/PhysRevLett.121.090503 or at arXiv:1803.04302.

30 Einstein's relativity leads to a ***separability criterion*** which states that "*since two far-out quantum systems no longer interact physically, at the time of the measurement of one system no real change can, earlier than what the finite speed of light allows, take place in its entangled partner as a consequence of this measurement or of anything that may be done to the first system*."

31 David Mermin, n his contribution to Jim Al-Khalili's book *Quantum. A Guide for the Perplexed* (Phoenix, 2003). The weirdness of quantum entanglement arises because it looks as though the possibly far-out entangled partner of a measured particle 'knows' that it was measured and what result it got, even when the rules of relativity tell us that there wasn't enough time for this. (I'll later explain this extraordinary feat by arguing that it stems from *supralness* or *in-binding*—i.e., from an in-causal binding, or a welding of the "yolks" of some particles: we'll see that the peculiar features of entanglement have something to do with what I call ***in-causation***.)

32 A more detailed account can be found in my 'Matter and the Poached Egg' paper, already cited. In it, we learn that two sources of entanglement—supra-conservation and quantum indistinguishability—are known. These are situations where Nature is in danger of becoming contradictory, but eschews trouble by weaving bonds of entanglement. (Quantum indistinguishability is troublesome because it raises a serious challenge to the applicability of the quantumhood principle.)

33 This theorem, called the no-signalling or no-communication theorem, distinguishes between an *influence* and a *signal* (a mere influence carries no explicit data that could be knowingly acted upon). This no-go or impossibility result explains why there is no "open warfare" and no practical contradiction between relativity and entanglement.

(c) A collapse is triggered by a quantum threat as I said. Entanglement opens the new possibility that even an unthreatened particle may collapse owing to a *shared* collapse prompted by a threatened particle entangled to it.

(d) *Two events that are quantum entangled are simultaneous and causally symmetric*[34]. So, two events are *not* quantum entangled if their ("Newtonian") simultaneity can be broken or if their causal link is not symmetric—i.e., is not reversible, both-way, or reciprocal. This remark will be helpful when we'll deal with the Schrödinger's cat experiment.

(e) Contrary to a widespread belief, a bond of entanglement is *not* forever. Recall from the "bare bones" that it can be severed by a *supralicide* collapse[35]. This being so, when a photon in an entangled pair hits a detector before its twin, the resulting collapse is shared by both photons and instantly cuts their bond of entanglement off. This remark casts the delayed choice quantum eraser experiment in a new light as we'll see.

(f) The nonlocality of entanglement is spatial and, given the spacetime continuum of our relativistic universe, *temporal* too[36].

Finally, I end this section about entanglement with this text of Marvin Chester, which argues that "*No element of reality is real*":

No element of the universe is truly isolated. An isolated system is a conceptual fiction: there are no such systems. Every element of reality is, in fact, part of some larger element within which it interacts.

Therefore it doesn't have a state.

Because it has no state, it's not real.

No element of reality is real!

How could one ever understand reality if its elements are unreal? Maybe one can never understand it through its elements[37].

A fuzzy cat, friends in disagreement, a bomb and an eraser

Now I shine the spotlight on a few landmark experiments that appear to uncover new aspects of quantum weirdness that boggle the mind[38]. I won't delve into their detailed accounts, which can easily be found on the internet and elsewhere. I start with Schrödinger's cat thought experiment. This *Gedankenexperiment* was dreamed up by Erwin Schrödinger in 1935 to highlight the strangeness of the "state update" that follows a quantum measurement[39]. In one version, a cat is put in a sealed steel box which also contains a radioactive atom and a deadly appliance triggered by the atom's decay. The atom is taken with a fifty percent chance to decay within the next hour. If it doesn't decay, the cat remains alive. One hour later, someone opens the box and peeks inside to examine the cat. This is where things get daft and murky! According to the mainstream interpretation of quantum mechanics, the atom and the cat in the sealed box are quantum entangled and evolve in a fuzzy or superposed state. The reason is straightforward: the cat is simultaneously alive and dead[40] because the radioactive atom to which it is entangled has and hasn't decayed simultaneously.

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34 By *causally symmetric* I mean that either event can trigger the other one, forthwith and both ways (these events are collapses, produced by a measurement or not). The bonds of entanglement being immediate and non-local, these events are *spacelike separated*. Hence, according to Einstein's theory, they "commute" and have no intrinsic temporal ordering. Whichever is considered to come first lacks objective significance.

35 Since they are supralicide, collapses often wreck entanglement and shatter its bonds. However, they can also *entangle* particles, for example through Bell-measurements. A Bell (or Bell-state) measurement is a joint measurement of two qubits, or quantum bits, which projects them onto what is called a Bell state. It is an entangling operation because the Bell states are themselves entangled (they are four maximally entangled two-qubit states forming a basis of the two-qubit Hilbert space). This operation creates entanglement-by-indistt because it plays on quantum indistinguishability. This game of supralicide and entangling (or *supralling*) measurements opens the possibility of innovative and sophisticated effects such as entanglement swapping and quantum teleportation (I analysed them in my already cited book in French, *Huit Leçons Essentielles*…).

36 In his book *Shadows of the Mind*, Roger Penrose comments: "*In fact quantum entanglement seems to be an effect that is quite oblivious not only to space separation but also of time separation*." Intriguingly, entanglement works even for particles *that have never existed at the same time*, as some experiments show. This raises issues that are beyond the scope of this article. I'll investigate the conundrum of quantum correlations across time in a future paper that will focus on the concept of time in physics.

37 Marvin Chester, *Primer of Quantum Mechanics*, John Wiley and sons, 1987.

38 I believe that the root cause of quantum weirdness is the "stuff-wave" (or wave of substance) nature of quantum waves. These have a knack to challenge Nature's consistency through their interference. This interference, which goes from constructive to destructive through every shade in-between, is not a "zero-sum game." This is what makes quantum waves potentially harmful (more, again, in 'Making Sense of Quantum Randomness').

39 Recall that the first order of business of a quantum measurement is to put the measured system in a fuzzy state (using the analyser of the measuring device). The second order of business is to threaten it (this is the detector's part). A collapse follows, which brings about a sharp state that is not threatened and yields a definite measurement result. This "state update" describes the (random) fuzziness-to-sharpness shapeshifting of the measured system in terms of subjective information.

40 The entangled system in the sealed box, which comprises the radioactive atom and the cat (and also, strictly speaking, the lethal appliance), is describable by a global and shared wave function which evolves according to the Schrödinger equation of quantum mechanics. This takes the cat to a bizarre state that is fuzzy and combines the two possible sharp states, since the atom to which it is quantum entangled is itself in a fuzzy undecayed-and-decayed state. In one state the cat is alive, in the other it is dead. Before the steel box is opened, the combined atom-and-cat state written in

However, when a human observer opens the box one hour later, the cat's wave function collapses. It shrinks from its fuzzy "cat-alive-and-cat-dead" state to either one of the sharp states available. In one, the feline is fully alive. In the other, it is truly dead. Jim Al-Khalili explains: "*Since the cat is also composed of atoms it should also be described by a wavefunction—a very complex one of course, but a wavefunction nonetheless. And since the fate of the cat is now strongly correlated with that of the radioactive nucleus, we must describe the two by an entangled state. Therefore the cat's wavefunction will unavoidably be split into a superposition of two states: one describing a live cat, the other a dead cat!*" I also heard or read the following explanation: "*Before someone opens the sealed box to watch inside, the radioactive atom in the box is in a superposed [or fuzzy] decayed-and-undecayed quantum state and the cat, because it is entangled to it, will be found in a matching alive-and-dead [fuzzy] state*[41]."

This conventional analysis of Schrödinger's cat experiment is flawed on no less than three counts.

The first flaw, or misunderstanding, has to do with the alleged entanglement—understood as *quantum* entanglement—existing between the cat and the radioactive atom. Granted, the state of the cat depends on that of the atom; but this relationship is *classical* and is not based on quantum entanglement. Remember, an entangled state is instantaneous and symmetric, or reciprocal. Here the cat-and-atom relationship is none of these. It is causally asymmetric since the atom's decay kills the cat but no state of the cat can, as such, trigger the decay the atom. It is not instantaneous either. The appliance that kills the cat if the atom decays is mechanical and chemical, not quantum mechanical. It could be designed so that, say, a decay would only kill the cat a good ten minutes later. This establishes that the atom and the mammal are *not* quantum entangled[42]. Observing the cat doesn't "measure" the atom and won't collapse it either!

The second misunderstanding lies in the claim that before someone opens the box and looks at the cat, the radioactive atom exists in a fuzzy state that combines two sharp states, one where it is whole or undecayed, the other where it is decayed. This view of the undecayed atom's state as sharp is mistaken. Instead, the undecayed atom is *as such* in a fuzzy state with respect to its energy level. It snaps to a random and sharp decayed state when it collapses[43]. The third misunderstanding, now, is perhaps the most surprising. It hinges on a confusion between genuine quantum fuzziness and fuzziness-by-ignorance. Here, the "cat-alive-and-cat-dead" state is the fuzzy *state-by-ignorance* that, before the box is opened, we fall back on for want of means to know better. It merely expresses our *ignorance* of what goes on inside the sealed box. A mere glance inside an open box doesn't generate a quantum threat and cannot shrink a cat to a sharp "either-live-or-dead" reality. It cannot collapse the atom either. Clearly, we merely update our knowledge in the face of visual evidence when we open the box and peek inside. This knowledge was already there, hidden in the sealed box and unbeknownst to us. The alive-and-dead cat was only a figment of our wrong-footed theoretical imagination.

My conclusion is consonant with the common-sense idea that sooner or later the radioactive atom will decay spontaneously, of its own accord, and regardless of whether a human observer opens the steel box. It does so because it is in a fuzzy state of its energy. Furthermore, the atom's fuzziness doesn't rub off on Schrödinger's cat, since the atom and the cat are not quantum entangled. Consequently, the mammal will never be in a state of suspended animation blending life and death. At all times, it will either be alive or dead, depending on the possible decay of the atom. This is what we expect from a real pet in the real world!

Our next experiment is the Wigner's friend experiment, a thought experiment dreamed up by Eugene Wigner in 1961. It adds a mind-bending twist to Schrödinger's cat experiment and goes like this. Alice, a friend of Wigner, agrees to perform a Schrödinger's cat experiment. We recall that according to the textbook interpretation of quantum mechanics, the cat in its sealed box is in a fuzzy live-and-dead state. We also recall that when Alice opens the box and glimpses inside, she sees that the feline is either fully alive or, alas, dead. Here Alice goes into the lab containing the cat's box while Wigner stays outside and can't know what goes on inside. (*Well, it seems that fuzziness-by-ignorance is staging a comeback!*) The twist is that Alice discovers whether the cat is alive or dead when she opens the sealed box at a time agreed with Wigner, but Wigner doesn't know anything. For him, the cat is still described

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symbolic notation reads: $|\Psi_{atom+cat}\rangle = \sqrt{½}[|atom_{undecayed}\rangle|cat_{alive}\rangle + |atom_{decayed}\rangle|cat_{dead}\rangle]$. When someone opens the box, she finds the cat either fully alive or truly dead. It is widely claimed that all this is what the rules of quantum physics force us to assert….

41 Jim Al-Khalili, *Quantum. A Guide for the Perplexed*, Phoenix, 2003. Note that if the cat were truly *quantum* entangled with the radioactive atom, it wouldn't be possible to talk about "*the cat's wavefunction*". Only a collective wavefunction, shared by the cat, the atom, and the deadly appliance, could be considered.

42 Besides, no supra-conservation law and no quantum indistinguishability come into play here, that would entangle the atom and the cat. Today however, mini 'cat states' or 'kitten states' are routinely created in laboratories, often using beryllium atoms, in such a way that the unstable atom and the 'kitten' are truly entangled.

43 An unstable quantum system is never in a fuzzy state that combines its decayed and undecayed states, just as a fuzzy state never mingles or superposes a wave state and a particle state. The undecayed state is fuzzy in energy, the decayed state is sharp in energy—and a particle state simply doesn't exist! Energy is singular. It plays a unique role in Schrödinger's equation through the Hamiltonian, which drives the wave evolutions. An unstable atom being fuzzy in energy, its energy has a non-vanishing spread ($\Delta E > 0$). This implies that its undecayed state has a finite average lifespan, making it unstable, as shown by the time-energy uncertainty relation (written $\Delta E.\Delta t \sim \hbar/2$). Only when the energy level is sharp or definite ($\Delta E = 0$) do we get an infinite duration, and hence a stable state (since $\Delta t \sim \hbar/2\Delta E$ = "$\hbar/0$" $\sim \infty$). An unstable atom may decay into a "generalised" sharp state comprising various 'daughter' particles, a transition best described in the formalism of quantum field theory. My main point here is that a fuzziness in energy is enough, *per se*, to elicit an inner quantum threat.

by a live-and-dead state *since he can't access Alice's knowledge*. As physicist Časlav Brukner pointed it out in the *Communications Physics* journal, "*After the friend's [i.e. Alice's] measurement has taken place, we are in a counterintuitive situation where Wigner describes the friend in a quantum superposition of observing two different outcomes, while from the friend's perspective a definite outcome must be perceived*." So, Wigner and his friend Alice end up predicting conflicting outcomes for the same fact or situation. Worse still, both are right, insofar as they stick to the textbook recipe. Some conclude that the truth of a fact, at least at the quantum level, is neither intrinsic nor absolute nor universal. It depends on where you stand. To quote the physicist Howard Wiseman, "*It could be that there are facts for one observer, and facts for another; they need not mesh*."

But wait… are we really talking about facts? Not so indeed. We are talking about *interpretations*. Remember, both Alice and Wigner are making statements about *assumed* facts that they can neither see nor control. On the one hand, Alice opens the box and finds, say, that the cat is alive. Granted, this is a fact. For Wigner on the other hand, the cat is still in a superposition of being alive and dead for a simple and straightforward reason: *he cannot and doesn't know*. For him, the animal is still in a fuzzy alive-and-dead state; yet *this is a theory-based interpretation, not a fact*. Plainly, Alice and Wigner have unequal levels of knowledge about the same fact, which is the state of the cat when Alice opened the box at the agreed time. Thes unequal levels feed the irreconcilable mismatch between their standpoints: this discrepancy is a sheer matter of ignorance. Note the added quirk that for Wigner, the fuzziness includes Alice herself. Her fuzzy state is a superposition of "Alice-saw-a-live-cat" and "Alice-saw-a-dead-cat".

As we gather, my take on this conundrum is that the Wigner's friend experiment, is not about reality itself, including in its more recent versions[44]. It doesn't show that absolute objectivity, or any other core assumption about the world, is not viable and should be ditched. Wigner's friend and Schrödinger's cat puzzles are created solely by our wrong-footed presuppositions. Our flawed understanding is what brings about fanciful and inconsistent facts that don't tally with reality. When we misconstrue a situation, we are courting conceptual disaster. My conclusion, Wigner and Schrödinger conundrums notwithstanding, is that truth and objectivity are still alive and kicking. It is hardly surprising that conflating fuzziness-by-ignorance and genuine quantum fuzziness leads to sham or 'Schein' paradoxes!

The next experiment is the Elitzur-Vaidman bomb test, proposed in 1993 by Avshalom Elitzur and Lev Vaidman[45]. This risky test is about finding whether some bombs are live bombs or duds. If they are live, a single photon is enough to explode them, because their detonators stand in the way of light and are extremely sensitive to it. If they are duds, they have no detonators that would hamper a photon that goes along their path. What makes the bomb test noteworthy is that it seems to show that at the quantum level, Nature can reveal facts about something through events that *might* have happened but *didn't* happen. Specifically, the experiment tells something about a path, or route, that a photon didn't take. Chris Nunn presents it as follows[46]:

> The bombs […] have extremely sensitive detonators that go off if hit by a single photon. To discover which bombs are live without detonating them it is possible to set up an apparatus, involving half-silvered mirrors, which send photons one at a time along two alternative routes. On taking one route, the photon hits the detonator; on taking the other it doesn't. The routes then rejoin. The apparatus is so constructed that, when a photon arrives at a point where the two routes then rejoin, it will always emerge from the junction in a particular direction if its wavefunction can take both routes. If its wavefunction cannot take both routes, the photon will only sometimes merge in this direction (instead of always), and sometimes will pop out in another direction.

Nunn adds:

> The wavefunction will always take both routes [whenever these routes are available]. The photon itself travels by one route or the other, but not both[47]. If the photon hits a live detonator, the bomb goes off and the photon is caught up in the explosion […]. The wavefunction can be assumed to have taken both routes up to the point the explosion occurred. It the photon goes the other way, there is no explosion and the wavefunction will take both routes provided that the bomb is a dud. If it's a dud, both channels are 'open', so to speak. The only thing that can close a channel and stop the wavefunction taking both routes is *if* the bomb *would*

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44 There exist more refined *Gedankenexperiments* around Wigner's friends. One of them is the *extended* Wigner's friend scenario, which involves four separate but entangled agents. They do not challenge my main conclusion, soon to be expressed. (See for instance 'Quantum theory cannot consistently describe the use of itself' by Daniela Frauchiger and Renato Renner, *Nature Communications*, 2018; DOI: 10.1038/s41467-018-05739-8; where they write: "*In this work we propose a Gedankenexperiment that extends Wigner's setup. It consists of agents who are using quantum theory to reason about other agents who are also using quantum theory*." Indeed, the agents are using the mainstream and textbook *interpretation* of quantum theory. This is the snag.) In some recent versions, the cat is harshly downsized and becomes a quantum bit, or qubit, whose sharp states are 0 and 1 instead of "cat alive" and "cat dead".

45 'Quantum Mechanical Interaction-Free Measurements', by Avshalom C. Elitzur and Lev Vaidman, in *Foundations of Physics 1994*, Vol. 23, No.7, 1993. Anil Ananthaswamy comments: "*For Vaidman, interaction-free measurements are the clearest indication that any theory that invokes a measurement-induced collapse of the wavefunction cannot be the correct theory. He's not the only one to think so*." (from Anil Ananthaswamy, *Through Two Doors at Once*, Dutton, 2019).

46 Chris Nunn, *de la Mettrie's Ghost*, Macmillan, 2005.

47 This sentence clearly shows that in the author's mind, the photon is a point particle, as in Bohm-de Broglie's theory.

> *have* exploded *had* the photon gone by the detonator route. In these circumstances, the photon can emerge from the junction in either direction.

Nunn then spells out the key point, which is easy to grasp if we have the experiment's setup in mind:

> So, if the photon emerges in the direction that implies the wavefunction could only take one route[48], you know you've got a live bomb, but you haven't caused an explosion. […] The wavefunction seems able to 'know' what would have happened if the photon had taken a route that in reality it did not take.

About the same experiment, Roger Penrose commented:

> Quantum theory allows for [...] a physical effect that results from the possibility that the detonator might have been wiggled, even if it was not actually wiggled! What is particularly curious about quantum theory is that there can be actual physical effects arising from what philosophers refer to as counterfactuals—that is, things that might have happened, although they did not in fact happen. […] How is it that [in quantum physics] the mere counterfactual possibility of something happening—a thing which does not actually happen—can have a decisive influence upon what actually does happen?[49]

In a video, Sabine Hossenfelder explains similarly: "*Suppose you have a bomb that can be triggered by a single photon if it is live, but it could also be a dud—this is what you want to find out without exploding the bomb. If it's a dud then the photon doesn't do anything to it but if it is a live bomb, then… boom! It explodes. Can you find out whether the bomb is live without blowing it up? That seems impossible but quantum mechanics makes it possible*." She then adds that it is possible because "*quantum mechanics tells you something about the path that the photon didn't take*[50]."

As we see, the bomb test experiment is peculiar in that it allows some photons to give away the presence of a bomb that, through its detonator, blocks a path or route *without* touching it, let alone going near it—or so it seems. It shows that sometimes[51] it is possible to carry out a quantum measurement *without ever interfering with the object we are measuring*. The whole shebang of interaction-free measurement is weird and baffling, but the facts are compelling: "*Quantum optics demonstrates the existence of interaction-free measurements: the detection of objects without light—or anything else—ever hitting them. […] Such interaction-free measurement seems to be a contradiction—if there is no interaction, how can there be measurement?*"[52]

Often a standard explanation is put forward, which says something like: "*One has managed to detect the presence of the ultra-sensitive bomb without triggering it, an impossible feat in classical physics. […] In the absence of the object, it is the wave-like nature of the incident quantum which [matters] through destructive interference […]; in the presence of the object, it is the indivisibility of the quantum which enforces the mutual exclusivity of the possible outcomes*[53]." Still, this hardly makes sense, and we may still wonder: Does Nature behave without rhyme and reason… or has some misunderstanding led us astray?

To answer, let me first point out that the Elitzur-Vaidman experiment doesn't deal with brute facts. It deals with *facts-cum-interpretation*, as with the Wigner's friend experiment. My view and analysis rests on these two ideas:

- The wave-like nature displayed by the photon which travels along both paths shows that no collapse happened, whereby the photon keeps moving in a both-path or both-route fuzzy state of its wavefunction.
- The common-sense view that "*the photon itself travels by one route or the other, but not both*," due to the alleged "*indivisibility of the quantum*" alludes to a point particle that doesn't exist, ever. Rather, "*the mutual exclusivity of the possible outcomes*" is a clue that a collapse happened and created the photon's one-route sharp state.

Accordingly, what is seen as an interaction-free measurement is but a sharp state resulting from a collapse that randomly shrunk the photon *away* from the detector[54], so that this state remains undetected and unrecorded. It is an example of *counterfactual* sharp states. Of course, the other possible sharp state offers a *factual* alternative, where the collapse shrinks the photon along the route containing the bomb—which then explodes. The bottom line is that the Elitzur-Vaidman bomb test is definitely *not* about what *might* have happened but *didn't* happen. It is only about a fallacy fed by an unacknowledged collapse that begat a *counterfactual* sharp

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48 It's inaccurate to say that the wavefunction could only take one route. One should rather say that the direction of the emerging photon is that of the (randomly chosen) one-route sharp state brought about by a collapse prompted the detonator, which acts as a detector. So a detonator is present, which means that the bomb is a live bomb.

49 Roger Penrose, *Shadows of the Mind*, Vintage, 1995.

50 Here is the YouTube link: https://youtu.be/RQv5CVELG3U?si=_df8c1wuOmAqCtaf.

51 I say 'sometimes' because, due to quantum randomness, this interaction-free measurement occurs only in 25 percent of the runs. However, the percentage is higher if the procedure is repeated. *See* 'Experimental Realization of "Interaction-free" measurements', by P. Kwiat, H. Weinfurter, T. Herzog, A. Zeilinger and M. Kasevitch, in *Symposium on the Foundations of Modern Physics 1994*, Editions Frontières, 1994; or in *Physical Review Letter* **74** (24): 4763-4766, 1995.

52 Excerpt from 'Quantum Seeing in the Dark', by Paul Kwiat, Harald Weinfurter and Anton Zeilinger, in *Scientific American*, November 1996.

53 'Experimental Realization of "Interaction-free" measurements', already cited.

54 Here the detector used in this measurement is the light-sensitive detonator of a live bomb.

state. On this insight, the bomb test doesn't display any feat of true "quantum magic." The mind-bending aspect of this spectacular experiment is no big deal: it only boils down to a few misconstrued facts that hoodwinked us. Much ado for almost nothing!

The bottom line is, broadly speaking, that a counterfactual outcome arises whenever, in an experiment, a collapse shrinks a fuzzy wavefunction *away* from a detector, since the resulting sharp state goes undetected and unheeded. Such counterfactuals are commonplace, as nothing compels collapse-driven sharp states to be factual!

Let's now go back to the two-slit experiment and ponder what would happen if the decision to switch the spying device on or off were taken *after* the photon went through the two-slit sheet or, in some versions, entered the two-arm interferometer. Will the photon adjust its behaviour to this decision *before* it is taken, as though it enjoyed some sort of foreknowledge? Or will it do so because the future, at least at the quantum level, can sometimes influence the past and the present? To find out, John Archibald Wheeler dreamed up his delayed-choice experiment, back in 1978, in which an observer's choice of how to measure the particle is done *after* a particle reached a critical bifurcation or forking point.

As usual, I won't give a detailed account of this experiment, which can be found in books, in published articles, and on the internet.

In Wheeler's experiment, the spying device of the two-slit experiment is switched on or off *after* the photon reaches the forking point in such a way that the photon cannot possibly "know" beforehand, as it moves past this point, what the future state of the device will be. Al-Khalili explains, considering an experiment that uses an atom instead of a photon:

> It is only when the atom is being watched that it remains as a particle throughout. Clearly the act of observing is crucial. [...] In what are known as 'delayed choice' experiments it is possible to have a detector in place and only switch it on after the atom has gone through the slits. [...] it needs only be switched on after the atom, behaving like a spread-out wave, has emerged from both the slits, but before it reaches the detector. Surely it is too late for the atom to suddenly decide to behave like a localized particle that has only passed through one of the slits. Apparently not. In such experiments, the interference is nevertheless found to disappear[55].

Wheeler concluded that, at least for photons, atoms and the like, we can rewrite the past by acting in the present, even when this past is billions of years away from now.[56] This is puzzling—is it a matter of retro-causality, or back-causation? Let's find out. In 2007, Wheeler's *Gedankenexperiment* was carried out by Alain Aspect and his team[57]. When the spying device was turned on *after* the photon went through the slits, no interference appeared even though one may have anticipated both-slit interference since, upon traversing the slits, the spying device was still off. However, this counter-intuitive result was as predicted by the theory. Again, we may wonder: Is it because the photon was already in the know, as it flew across the sheet with the slits, about the experimenter's *later* decision to switch the spying device on? Or is it because some future events can influence the present behaviours of photons and the like? In short, is foreknowledge or back-causation at work here?

None of these. Indeed, to explain the eraser experiment, we only need to be aware that a collapse is a fuzziness-busting event that, when an interferometer is used, shrinks the photon from a fuzzy "both-arm" to a sharp "which-arm" state. We actually need to remember two things. The first one is that, if a detector threatens it, a photon or an atom collapses and shapeshifts from a fuzzy to a sharp state. It then looks like a localized particle. The second thing is that this shrinking of the quantum system *in the present*, from fuzzy to sharp, doesn't require any backwards travel to the forking point *because it is not a localized object*. Instead, the vanishingly small—but still-interfering—overlapping tails of the which-arm sharp components within the fuzzy state ensure that the collapse bring the photon or the atom in one of these sharp states, exactly as if it had "*only passed through one of the slits*."

Let me stress it again: a photon spread over the two arms of an interferometer isn't split in two half-photons moving their separate way with no mutual interference. This fuzzy photon it is still whole, since the quantum waves of its half-photons keep interfering

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55 Jim Al-Khalili, *Quantum. A Guide for the Perplexed*, Phoenix, 2003. Recall that a which-path photon isn't a point particle. It is a photon in a sharp state, which is as wave-like as its fuzzy (both-path) counterpart. The same goes, more generally, with any quantum system.

56 John Wheeler considered a *cosmos-wide* delayed choice experiment based on gravitational lensing. (*Gravitational lensing* is a relativistic phenomenon where a massive body in the universe—e.g. a star, a quasar, a galaxy, a black hole—warps space-time so that light-beams are locally deflected towards it.) A "lensed" photon may travel huge distances in a fuzzy state, only to end up collapsed or shrunk in one or another sharp state *perhaps a billion years later* in its journey, when it hits the Earth and is measured. Some believe that the photon travelled all the way in a sharp state—and even as a localized particle instead of as a wave—as though it 'knew' ahead of time that it would be measured. Others believe that its measurement *now* could have influenced its state *then*, a billion years ago or more. In the textbook *Quantum Mechanics*, by G. Auletta, M. Fortunato & G. Parisi (Cambridge University Press, 2009), we read: "*We can choose here on Earth either to observe an interference phenomenon (wave-like behavior), hence merging the light from both paths and detecting the outgoing beam, or to detect the light on a determinate path (corpuscular behavior). At first sight, it is as if we could decide here and now a certain (wave-like or corpuscular) behavior about an event which seems* to have already happened *millions of years ago*."

57 This experiment used a Mach-Zehnder interferometer (MZI) with two arms 48 metres long. Recall that a MZI is a more sophisticated equivalent of a two-slit sheet or half-silvered mirror. It has two arms that send particles along two paths—one path for each arm—just like a half-silvered mirror splits a photon into a transmitted part and a reflected part.

mutually through their overlapping tails[58]. That these tails are wont to be very remote and exceedingly faint is immaterial. Owing to them, the photon will react *as a whole* when a detector threatens one of the half-photons. It will randomly shrink to a possible sharp state, which is any half-photon. Then, no interference pattern will show up, as expected since a which-arm photon implies a lack of interference. Only a fuzzy photon may give rise to interference. I therefore disagree with statements such as: "no *which-path information implies interference, whereas* potential *which-path information, even if never obtained by the experimenter, destroys it*"[59]. No which-path information—that is, both-path information—*results* from fuzzy states. Which-path information, potential or otherwise, *results* from sharp states (and is never linked to point particles). it is crucial to get these causal implications right, if we are to get a handle on the quantum world.

From the above we can safely conclude that there is no need, in a delayed choice setting, to assume that a point particle runs backwards in time to a forking point, to adjust its past behaviour to a later switching on of a spying device. Nor is there any need to assume back-causation. Such a tiny and well-localized particle is nowhere and nowhen to be seen! This settles the issue in a way that doesn't hurt common sense.

The Scully-Drühl experiment is my last experiment. Its intricate and complex setup (which, again, is detailed in books, published article and on the internet) includes a two-slit sheet as in the two-slit experiment. It also includes an optical crystal[60] placed after the sheet to create pairs of "near" and "far" entangled photons from 'pump' photons. When a photon in a pair is identified by which slit it went through, we know that its entangled twin went through the same "which slit". A maze of mirrors, beam splitters and detectors is the remaining part of the setup, laid out so that a "near" photon ends up detected by the "near" detector D_0 while its "far" twin goes to either one of four "far" detectors. Two of them, labelled D_1 and D_2, are which-path, which-slit or which-way detectors (also called *Welcher-Weg* detectors). They click when it is known which slit the photons came from. The remaining two, labelled D_3 and D_4, are both-path or both-way detectors. They click when the which-way information of the "far" photon is scrambled and lost. Then, only both-way information can be had. The slits and the paths of both photons are said to be indistinguishable. Note that for each 'pump' photon evolving into an entangled pair of "near" and "far" twins through the optical crystal, a joint detection is made of the "near" photon at D_0 and of the "far" photon at any of the D_1–D_4 detectors.

A click of detectors D_1 or D_2 provides which-way information about both the "far" photon and its entangled "near" photon. When this information is scrambled or *erased*, one of detectors D_3 and D_4 clicks. Crucially, the optical distance of the "near" detector D_0 from the slits is 2.5 m shorter than that of the "far" $\{D_1, D_2, D_3, D_4\}$ detectors. Thus, a "near" photon arrives at D_0 about 8 ns *before* its matching "far" photon. The choice to preserve or erase the which-path information by manipulating the "far" photon is therefore made when its "near" twin has *already* been measured and registered by D_0. This is the catch!

The Scully-Drühl experiment combines two aspects, namely:

(a) *The eraser aspect*: the quantum eraser manipulates the "far" photon in a way that wipes out the which-slit or which-path information that was initially available. Path indistinguishability and both-path interference result[61].

(b) *The delayed-choice aspect*: the decision to erase or not the which-slit information carried by the "far" photon is taken *after* its "near" twin arrived at detector D_0.

Running the experiment, we find that the "near" twins of "far" photons detected at D_3, which reveals a lack of which-path information, build a collective interference pattern at D_0. The same holds true for the other both-way detector, D_4. Contrariwise, no interference pattern is found at D_0 when "far" photons are detected at a which-way detector (D_1 or D_2). It thus appears that the behaviour of the "near" photon at D_0 correlates to—*or is determined by?*—whether its "far" twin is measured at a detector that preserves the which-path information (i.e., at D_1 or at D_2) or erases it (i.e., at D_3 or at D_4). The baffling bit is that it is so even though the "far" photon is detected a while[62] after its entangled "near" photon hit D_0 where it was observed and recorded. This suggests that future and present decisions can influence past events, since the later choice to erase or not an information carried by a "far" photon seem to retroactively influence how its entangled "near" photon collapsed earlier (at D_0). This is odd.

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58 Some contend that a photon "*travels no distance in no time*", which is no mean feat for something known to travel at the top speed ever! This is justified by the relativistic phenomena of time dilation and length contraction which, extrapolated to the photon, say that time stands still, and distances shrink to nought. However, this argument doesn't wash, since time dilation and length contraction only hold for objects and observers to which an *inertial* frame of reference can at times be attached *because they have mass*. This, clearly, is not the case for the *massless* photon.

59 Excerpt from *The Quantum Divide*, by Christopher C. Gerry and Kimberly M. Bruno, Oxford Univ. Press, 2013.

60 This crystal is a non-linear optical beta barium borate (or BBO) crystal, the chemical symbol of which is $\beta{-}BaB_2O_4$ if you want to know. Sometimes it splits or converts a 'pump' photon (arriving through either slit) into two lower energy photons. This process is called a *spontaneous parametric down conversion*. Because of the way they are produced, these 'daughter' photons are constrained by a *supra-conservation law* which entangles them and feeds interference. Specifically, these down converted (and fuzzy) siblings are entangled because they share a constraint of momentum conservation (whereby the vectors representing their respective motions add up to equal that of the 'pump' photon).

61 This indistinguishability begets *entanglement-by-indistt*, as explained in my 'Matter and the Poached Egg' paper already mentioned.

62 Barring technical difficulties, this "while" can be made arbitrarily long, much longer than 8 ns (*ns stands for nanosecond*).

The delayed choice quantum eraser is made even more puzzling by our poor understanding of the fuzziness-sharpness duality, as this comment shows: "*So we can say in [the which-way] case, without fear of paradox, that each photon went through just one path through the beam-splitter. In fact, if the photon were to take both paths, it would be hard to understand why it should appear to have taken just one of the two paths, why, that is, it is detected at [one detector only] rather than at both [detectors]*[63]."

However, I failed so far to mention an important detail, which is that no interference pattern is ever seen at D_0. This is consistent with the fact that when the "near" photons hit D_0, the which-way information hasn't been erased yet. Consequently, "near" photons cannot form interference patterns at D_0, only clump patterns that don't give which-way information. It is so whether the "far" photons later end up at a which-way detector or at a both-way detector[64]. Indeed, as Arvin Ash points out, in this experiment "*you're not changing the past. What you are really doing is, in the future, you are choosing a subsample of the data you made in the past*[65]." In the same vein, Sabine Hossenfelder stresses that the delayed-choice quantum eraser "*doesn't erase anything, and certainly doesn't rewrite the past*." She argues that the interference pattern found at detector D_0 *"really comes from selectively disregarding some of the particles. That this is possible has nothing to do with quantum mechanics*[66]."

We also learn from Wikipedia that "*an interference pattern [at detector D_0] may only be pulled out for observation after the ["far" photons] have been detected. [Besides,] the total pattern of ["near" photons at D_0] never shows interference, so* it is not possible to deduce what will happen to the ["far"] photons by observing the ["near"] photons alone." And then, "*the delayed-choice quantum eraser does not communicate information in a retro-causal manner because it takes another signal, one which must arrive by a process that can go no faster than the speed of light, to sort the superimposed data in the ["near"] photons into four streams that reflect the states of the ["far"] photons at their four distinct detection screens*." Clearly, for all its weirdness, Nature seems loath to let us tamper with the usual cause-and-effect chronology.

By way of conclusion, I propose the few points below to make sense of the delayed-choice quantum eraser experiment:

(1) Both-path (or both-slit, or both-arm) information refers to a fuzzy state of the wavefunction.
(2) Which-path information refers to a *wave-like* sharp state often resulting from a sharpness-yielding collapse[67].
(3) A measurement apparatus comprises an analyser and a detector. The analyser generates fuzzy states. The quantum threat producing detector begets sharp states through collapses, as I stressed repeatedly.
(4) On becoming operationally indistinguishable, two photons, say, become quantum entangled[68] and yield interference effects.
(5) Measuring any one of two entangled particles collapses them both simultaneously and, as a rule, disentangles them[69].

Putting all this together leads to conclude that a fuzzy two-arm photon travelling in an interferometer in two bits, or two half-photons,[70] may later be found in a sharp which-arm state in a delayed choice setting *without having to fly backwards to the forking point in space and time*[71].

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[63] Peter Gribbins, *Particles and Paradoxes*, already mentioned.

[64] Technically, it is because two interference patterns arise at D_0 when the matching "far" photons are fuzzy (and hence 'both-way')—one for those which ended up at D_3 and one for those ending at D_4—are "out of phase". They are mutually shifted and add up to a (no-interference) clump pattern. When the "far" photons are sharp (and hence are 'which-way'), those landing at D_1 and those hitting D_2 add up to a similar clump pattern.

[65] From the Arvin Ash YouTube video: 'Boy, Was I Wrong! How the Delayed Choice Quantum Eraser Really Works'.

[66] From the Sabine Hossenfelder's 'The Delayed Choice Quantum Eraser, Debunked' video (https://youtu.be/RQv5CVELG3U?si=_df8c1wuOmAqCtaf). The two interferences patterns found at detector D_0 are build (post-selectively) from "near" photons whose "far" twins ended up at D_3 on the one hand, and from those whose "far" twins that were detected at D_4 on the other hand. These patterns add up to a clump pattern, as noted before.

[67] Recall that *both* fuzzy and sharp states are states of a wavefunction and thus are equally wave-like. Point particles are nowhere to be seen in the quantum world. They are just figments of our (classical) imagination.

[68] Again, quantum indistinguishability begets quantum entanglement (of the *entanglement-by-indistt* kind) to safeguard Nature's consistency. Again, see 'Matter and the Poached Egg' (https://galileocommission.org/can-we-crack-the-mind-body-problem-part-ii-emmanuel-ransford/?swcfpc=1).

[69] Their global and simultaneous collapse means that their shared wavefunction collapses at once and in its entirety. Specifically, when the "near" photon is detected at D_0, the collapse involved is immediately shared by its "far" entangled partner. This is the first collapse of the "far" photon, ahead of the one occurring some 8 ns later at any of the {D_1, D_2, D_3, D_4} detectors. It may disentangle the "near" and the "far" photons since the collapse can be *supralicide* (besides, the "near" photon is often absorbed at D_0 and doesn't even survive).

[70] This photon in a fuzzy state of its wavefunction is spread out in two bits—in two (pseudo) half-photons—that can be hugely distant if the interferometer's arms are wide apart. It is still whole nevertheless, in the sense of *quantumhood* or wave wholeness, which means that the two bits keep interfering mutually. We recall that they do so through their remote, and undoubtedly exceedingly faint, overlapping tails. So, at this stage, there is no quantum threat, and no collapse is in order.

[71] I'll come back to this in a future paper that will address the broader issues of time and causation in contemporary physics.

Two friends and one foe

In the game of existence, and more precisely in the game of "coming-into-being", two constraints stand out. One is self-sufficiency, which means that whatever exists concretely does so *because*, deep down, it is self-sustaining. Whatever exists does so because—at the deepest level, that of its particles and atoms—it makes or generates itself[72]. To flesh out this idea, I liken it to an unknown animal about which we only know that it can fly. This ability, as such, reveals that the animal has what it takes to fly: wings, muscles, nerves and what have you. Similarly, to exist means to be endowed with the ability to self-beget or "bootstrap" oneself into existence. (Really, this statement is no more than a tautology or a truism.) Concrete existence would thus depend on a dynamical process of self-begetting. A concrete being, ultimately, *is* itself such an unfolding process. On this insight, whatever exists is dynamical in essence. It is never at rest. Sometimes I express this idea by saying that "stillness is death". Inner stillness is nonexistence! It turns out that quantum waves fit the bill but not point particles, that provide no wiggle room for an inner dynamical process to unfurl[73].

The other constraint sees to it that nothing trumps Nature's *concrete* consistency, or else, that *harmful* contradictions have no currency in the game of existence. Nature simply cannot afford to be contradictory. Yet, in the real world, in all its glorious diversity, there is no shortage of potential contradictions and inconsistencies. Handling them and getting rid of them can be a tall order; so that Nature, if I may say so, needs an efficient anti-contradiction immunity to do the job. When a risk of harmful contradiction arises, its immunity comes into play. As far as we can say, it always gets the upper hand[74].

It turns out that **Nature's anti-contradiction immunity has two friends and one foe**. The first "friend" is a no-brainer. It is about situations that are contradiction-free. The second "friend" encompasses situations characterised by an implicit or *blind* contradiction (to be defined shortly). The "foe," finally, relates to situations marred by hard-boiled contradictions that lead to genuine paradoxes. It is a crushing spoiler of Nature's soundness and reliability. The foe is very harmful and cannot be left to its own device. Accordingly, Nature's anti-contradiction immunity will go at any length to nip it in the bud. Its winning trick is to tame hard-boiled contradictions into becoming blind contradictions. This is much easily said than done, yet Nature pulls it off by means of amazing feats of innovation. Quantum entanglement and the wavefunction collapse are such feats as we saw, and so are the three fundamental interactions[75] known to quantum field theory. So, too, is the absoluteness of accelerations[76]. Indeed, Nature's taming of hard-boiled contradictions sheds light on many facts and phenomena that are *prima facie* weird and downright inexplicable.

What are blind contradictions? They are contradictions that exist in an abstract or theoretical way and stem from incompatibilities between various laws and aspects of the real world, yet fail to jeopardize Nature's concrete or practical consistency. They are part and parcel of Nature's make-up and can't be removed. Since, to all intents and purposes, they are harmless, Nature's anti-contradiction immunity, again if I may say so, is unfazed and turns a blind eye to them (hence their name). Blind contradictions are often hidden under a veil of ignorance due to a *local* lack of objective information about a situation which, *globally*, is contradictory[77].

Two people of the same height who walk away from each other provide an easy example. Each will see the other, at a distance, smaller. Yet, they can't be both smaller than the other, so we have a contradiction. What saves the day is that this *relational* contradiction is not concrete. It is purely a matter of knowledge, of awareness of a reciprocal effect of perspective—the perceived smallness depends on the *local* context and is neither intrinsic nor absolute. No "contradictory injunction" is incurred, that would

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[72] Self-begetting or self-building is a matter of "active reflexivity", whereby something creates itself through its intrinsic or inner motion (in the matching space-time). This "active reflexivity" shuns the infinite regress that bedevils the usual way of explaining a thing or an event B from a causal antecedent A. This way is formalized by the so-called *modus* (*ponendo*) *ponens* of logic, which can be articulated as follows: (1) $A \neq B$, (2) $A \Rightarrow B$, (3) A exists or is true, (4) Therefore, the existence or truth of B is established (it is explained by that of A, which itself… here comes the infinite regress!).

[73] The point particle is thus ruled out as "ontologically aberrant". Incidentally, the de Broglie-Bohm theory is also ruled out, since it rests on this notion (it is a point particle-cum-pilot wave interpretation of quantum physics). Another feature of this theory which, I think, barely makes sense is the special and prominent role it gives to the position observable. There is no robust justification for It in physical reality.

[74] Arguably, the "*unreasonable effectiveness of mathematics in natural sciences*" underscored by Eugene Wigner (and also by Galileo Galilei, with his statement that "*Nature is written in the language of mathematics*") has much to do with Nature's consistency which, I suspect, could well be undecidable—as mathematical consistency is. (On this issue and on the related one of ***undecidedness***, see the Appendix 3B of my paper 'Psychism, the Deed, and Beyond', at https://galileocommission.org/can-we-crack-the-mind-body-problem-iii-emmanuel-ransford/?swcfpc=1.) If so, the conjectures of Stephen Hawking, Roger Penrose and Igor Novikov regarding Nature's and the universe's consistency are bound to remain conjectures.

[75] These interactions are the electromagnetic, the weak nuclear, and the strong nuclear forces. According to their description by gauge theories which explore what happens when a so-called *global symmetry* is replaced by a *local symmetry*, these interactions are necessary to keep Nature altogether fruitful and consistent (see my 'Psychism, the Deed, and Beyond' paper, already mentioned). Such examples of interactions that arise to keep Nature contradiction-free are aplenty. They include the centrifugal and Coriolis forces (in rotating systems). They also include the blending of the electric and magnetic fields into an electromagnetic field, and the weaving of space and time into Minkowski's space-time continuum…

[76] If accelerations were relative as velocities, the twin paradox of special relativity would be a genuine one since the situations of the twins would then be symmetrical and interchangeable. These twins would *really* be both younger and older than their sibling! Nature would be contradictory.

[77] An object falling behind the event horizon of a black hole illustrates the notion of veil of ignorance. The speed of this fall is *locally* very different for two observers, one standing inside the event horizon and the other outside. However, the inside and the outside can't swap information. This creates an airtight veil of ignorance which ensures that local eyewitnesses on both sides of the horizon will never share information about the fall.

locally and *concretely* tug at people or at anything else, and wreak havoc. In that sense it is *blind*. Other examples can be worked out from the relativity of simultaneity which comes into play when inertial observers move in different frames of reference[78]. These observers may have conflicting but equally rightful *local* and *relational* perceptions as to whether some events A and B happened at the same time, or A before B, or B before A. Still another example hinges around the glaring incompatibility which appears to exist between relativistic locality on the one hand and the instantaneity of entanglement on the other. However, entanglement can't be used to send signal at speeds faster than that of light (*see the Box*).

BOX: From foe to friend: the case of faster-than-light influences

Let's call a *foe* of Nature's consistency and anti-contradiction immunity any physical situation where a hard-boiled contradiction arises in the physical world. Nature can't withstand such an enemy whose impact would be devastating. Fortunately, it can tame it. The instant correlations of a pair of entangled particles are a case in point. These correlations make it possible to bring about a faraway event—a collapse-prompted shrinking event—earlier than what the relativistic limit on velocities permits. For example, measuring here and now the spin of a fuzzy electron shrinks it, but it also collapses forthwith the spin of another electron entangled to it, maybe in a distant galaxy… as though space-time were Newtonian! This instant collapse is shared between the two electrons and shrinks their fuzzy states of spin to sharp ones, in a *concerted*, simultaneous and correlated way. The catch is that Einstein's relativity rules out *any* instant non-locality, so that the long-distance impact or influence of entanglement, which creates these correlated nonlocal states, plainly violates relativity. This smacks of hard-boiled contradiction. Will Nature cope, and how?

Amazingly, this contradiction wreaks no havoc to the causal fabric of reality because the nonlocal correlations of entanglement are of a restricted kind that combines the *non-locality of influences* with the *locality of signals*[79]. Signals have an information content that can be deciphered and exploited causally, whilst influences do not carry meaningful information. Therefore, *influence* non-locality doesn't deliver information[80] that could be acted upon, so that no *operational* conflict arises between entanglement and the laws of relativity. The contradiction at issue is a *blind* contradiction[81], and entanglement affords no causal short-cut ahead of time. Its nonlocal influences are blurred and hidden under a veil of ignorance which is that of quantum fuzziness[82]. Therefore, even though the non-local simultaneity implied by entanglement doesn't sit well with relativity and openly flouts its rules, Nature remains consistent. This is quite an achievement!

A whiff of sentience, here and there and elsewhere

The riddle of the conscious brain is a notoriously tough nut to crack. As yet, the rabbit of conscious awareness didn't let itself be pulled out of a theoretical hat, despite some overoptimistic claims to the contrary. It remains shrouded in mystery; and really, we don't even know what consciousness is. A sophisticated string of words which says that "*consciousness is just a giant self-referencing complex adaptative system at the end of the evolutionary chain*"[83] is alluring but doesn't explain much. It leaves us none the wiser.

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78 The relativity of simultaneity, in Einstein's special relativity, creates countless blind contradictions that challenge our intuition but do not yield true contradictions because, as David Bohm explains, "*The relativistic failure of different observers to agree on simultaneity in no way confuses the order of cause and effect, provided that no signal can be transmitted faster than light*." (David Bohm, *The Special Theory of Relativity*, Routledge Classics, 2009.)

79 Signal locality sees to it that the nonlocal correlations of entanglement cannot be used to send superluminal signals. Indeed, "*instantaneous communication between distant objects, or nonlocality, is a general feature of the quantum world, and can be traced back to the nature of the wavefunction itself. Most physicists are not too bothered by this since quantum nonlocality can never be used for faster-than-light signalling—in violation of relativity theory—due to the inherent probabilistic nature of the quantum world*." (Jim Al-Khalili, in *Quantum. A Guide for the Perplexed*, Phoenix, 2003.) Here the veil of ignorance is due to the fact, writes Partha Ghose, that "*as long as causality and unitarity hold, expectation values of [quantum] observables cannot change as a result of state vector [aka wavefunction] reduction or collapse, ensuring signal locality in spite of [entanglement's] nonlocal correlations*." (Partha Ghose, in *Testing Quantum Mechanics on New Ground*, Cambridge University Press, 1999.) Ghose adds that "*the issue of superluminal signalling and its incompatibility with relativity can be meaningfully discussed only […] in relativistic quantum field theory*."

80 By 'clear-cut information' I mean *causally* usable information, in the sense of explicit and reliable data (or signal) that could have a causal impact, possibly by pointedly motivating specific decisions and inducing specific actions.

81 At a deeper level, this lack of operational conflict is because *nothing travels* here. Nothing is sent out. Nothing is forwarded and nothing moves. It is because, in the framework based on in-causation and holomatter, entanglement is due to *in-binding* or *supralness* as I already said, so that the non-local correlations resulting from the shared collapse of entangled systems are produced by a collective and simultaneous switching of the (relativistic) *matter* guise of holomatter to its (a-relativistic) *paral* guise—not by a propagation of any sort. No information transfer from one place to another, which would then have to be faster-than-light, is involved. Recall in passing that the *paral* guise transcends the relativistic space-time of ordinary matter in a way that makes it distance-blind.

82 The so-called no-signalling or no-communication theorem demonstrates this no-go result. The veil of quantum fuzziness—which allows *influence* non-locality but not *signal* non-locality—is due to the probabilistic randomness of the quantum world, which is mirrored in the probability distributions that arise in the theoretical description.

83 From Murray Gell-Mann's book *The Quark and the Jaguar*, Little, Brown and Co., 1994.

Some would quip that it is not even wrong. Instead of delving into the daunting issue of consciousness, I'll focus on the telltale marks that psychism and consciousness may leave in the material world. My core assumption, which says that quantum randomness is in-causation hiding in plain sight, suggests that a quantum collapse, being random, happens when the genie of in-causation jumps out of the bottle of its latency. It would be driven by the in-causal part of the elementary particle[84],then active. Sometimes, I call 'psi' this putative psychic dimension.

The concept of ***holomatter*** follows. It is a two-sided stuff which adds an in-causal and psychic dimension to ordinary plain matter. It assumes the coexistence, in the substance we think of as plain matter, of an out-causal dimension that is smooth, relativistic, and deterministic, and of an in-causal dimension that is discontinuous, a-relativistic, and random-looking. As we saw, the in-causation hypothesis casts new light on quantum collapses and quantum entanglement. Could it also unlock the long-standing riddle of the conscious brain?[85] My hunch is that our thoughts and the stream of our consciousness have something to do with the in-causal dimension of holomatter. The brain would play host to the mind by arousing or kindling some of its in-causal "yolks" out of their latency, on large enough a scale. Can this idea lead to a possible *explicatory* theory of sentience and of brain-based awareness? I already broached this topic elsewhere[86], For instance, I wrote:

> The 'psi' parts of elementary particles would be the raw building blocks of higher level, macropsychic conscious experience. This idea […] leads to the *cognitive iceberg* model of perceptual awareness. This *iceberg* is made of an underwater—or rather, an "underaware"—part, where incoming sensory stimuli are coded into specific patterns that I call the *suprels*; and of a 'tip'. Visual *suprels*, for instance, are made in the visual cortical areas, where they stay unconscious. Then they dash to the 'tip', where they target key microstructures—dubbed the *paralgens*—that squeeze out of them the multifarious subjective contents of experience known as *qualia*. (It turns out that some paralgens are likely to be tucked inside the postsynaptic NMDA receptors found on the dendritic synapses of large pyramidal cells in the neocortical fifth layer…)[87].

The 'psi' parts are the in-causal and psychic "yolks" of (holo)particles. In the *paral* guise of holomatter, these 'psi' parts are no longer latent. They are active, and they become the ***dancing specks of sentience*** of the title. My assumption here is that the individual level of sentience of the individual 'psi' parts is exceedingly low—and really, *unconscious*—in the *matter* guise and goes up a notch in the *paral* guise. This level would rise further when many 'psi' parts blend into a broader community through in-binding, and hence through entanglement (by means of a welter of 'psi' threads). As for the notion of *suprel*, it has to do with the patterns made by binding the psychic parts, or "yolks", of (holo)particles. It does not relate to their material parts, or "whites"[88]. This "in-binding," or ***supralness*** as I call it, would underpin quantum entanglement as I already suggested. Indeed, the cognitive iceberg model

> sheds new if provisional light on such conundrums as: the binding problem (which deals with the uncanny, seamless oneness of conscious experience); the nature of our conscious recalls; the parallel (and unconscious) *versus* serial (and conscious) processing problem; and finally, the 'upshot problem', whereby what we are conscious of appears to be the end-result, or upshot, of neural computations—rather than the computations themselves. […] The stunning conclusion—consonant with the teachings of many mystics and traditions—is that we belong to a universe-wide psychic field.

Some additional explanation is in order:

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84 Recall that I assume that an elementary particle (an electron, photon, proton or rather quark, …) is a particle of holomatter or (holo)particle that I liken to a poached egg whose "white" is its material part and whose "yolk" is its psychic part. The former is visible, deterministic, smooth, wave-like, and relativistic. The latter is hidden, random-looking, discontinuous, wave-less, and a-relativistic. Somehow, the in-causal, random and psychic "yolk" is 'piggybacked' on the out-causal, deterministic and material "white". These two sides are complementary components of particles that, like the two sides of a coin, cannot be wrung apart. A collapse is a non-unitary event and has many names to it, including quantum jump or leap.

85 My focus is on some aspects of *ordinary* brain consciousness. I say *some* aspects and *ordinary* consciousness, because I'm aware that NDEs, shared-death experiences, OBEs and other phenomena take us beyond ordinary consciousness. According to Melvin Morse, a practicing pediatrician, "*NDEs are a wake-up call reminding us that we are interconnected spiritual beings as well as unique individuals*" (from his best-seller *Where God Lives*, Cliff Street Books, 2001). NDE means near-death experience and OBE means out-of-body experience.

86 On the issues of the mind-body problem and of brain consciousness, see for instance my papers 'Quantum Panpsychism and the Light Bulb Metaphor' posted on the Galileo Commission website (https//galileocommission.org/quantum-panpsychism-and-the-light-bulb-metaphor-emmanuel-ransford/) and 'Psychism, the Deed, and Beyond' (https//galileocommission.org/can-we-crack-the-mind-body-problem-part-iii-emmanuel-ransford/?swcfpc=1). In French, see my books *L'Origine quantique de la conscience* and *Huit Leçons essentielles sur la science quantique*.

87 This passage and the next one are from my text 'Panpsychism, Conscious Brain, and Beyond', in *Science and the Primacy of Consciousness* (The Noetic Press, Orinda, CA USA, 2001). These *paralgens* are like catalysts of paral. Perhaps some are tucked away in some post-synaptic ion channels in the cortex. They would have flows of particles and ions—such as the ubiquitous Ca^{2+} ions—shift momentarily to the paral guise as they dart through. The 'psi' parts or psychic components involved would then be kindled or awakened out of their latency. The resulting level of awareness would be harmonized and enhanced by the broader network, in the brain, of countless bonds of entanglement (or, in "holomatter-speak", of countless 'psi' threads, or bonds of *supralness* or of *in-binding*). The ability to produce large flows of entangled paral—which I also dub *supralled paral*, or ***supparal*** for short—could be the utmost and most precious secret of our biological brain.

88 Recall that in the poached egg metaphor, the psychic or 'psi' part of the (holo)particle is in-causal and hence random. It is a hidden " yolk". The material part is out-causal and hence deterministic. It is its conspicuous "white".

> *Supralness* [and hence, quantum entanglement] is a glue that binds or aggregates the [in-causal] parts of [holoparticles]. A *supral link* is a kind of [psychic or 'psi'] thread, running through the [in-causal and psychic] parts of two or several [holoparticles]. It unifies and weaves them into an overall fabric. […] 'Psi' threads weave a wealth of tangles and webs. They bring patterns—or structure—to bear at the [psychic] level. (This structure is combinatorial and topological in essence.) The point is that structure means information: these webs and tangles encode information, whose richness and variety are virtually boundless. […] Think of all the patterns that can be wrought by linking a basketful of beads with threads! Of course, this information is psychic in essence, since it is stored and carried in the 'psi' field. I call *suprels* the elementary bits, or units, of it. Suprels are basic data-coding [psychic] patterns. Our feelings, thoughts and memories would arise from them.[89]

If our memory—I'm talking about the *declarative memory*, that of our conscious recollections—is s*upral* in essence, with suprels as "engrams", then it is not localised like that of computers. Interestingly, the neurosurgeon Eben Alexander tells us that

> The general idea in conventional neuroscience is that memories are diffusely stored throughout the neocortex. Yet the overall experience of neurosurgeons who have resected large regions of the neocortex from every lobe of the brain in countless patients over the last century for myriad pathological conditions (brain tumors, epilepsy, aneurysms, malformations of the brain's blood vessels, and infections, among others), without encountering patterns of broad memory loss in their patients, belies the notion of the general cortical storage of specific memories as false.[90]

The holomatter approach suggests a solution to the mind-body problem which goes roughly as follows:

> Is there any room for a possible mind-body interaction within [the holomatter] framework? […] I call the core mind-body interaction the **deed**. It would underpin the sensory-motor interplay [of] the animal kingdom. We seem hopelessly clueless about the deed; but things look much brighter if we surmise that ordinary matter is out-causal while psychism is in-causal. Then there's an obvious lead: to pin down the deed, look no further than [at any holoparticle], and find out whether and how its [out-causal and in-causal parts] jolt each other. […] if holomatter holds any water, [the deed] is etched in the makeup of elementary particles—and it was hiding in plain sight all along! We failed to spot it because we mistook holomatter for plain matter[91].

Within the holomatter framework, the biological brain is seen as a kind of lightbulb that would produce consciousness instead of light. This doesn't imply that sentience and conscious awareness are material in essence. My stance is clearly that brain consciousness isn't a mere side-effect of matter and cannot be reduced to it!

Now, and finally, I'll briefly broach the issue of what holomatter means and entails for each of us, given the fantastic resources that go with it. If our universe is made up of holomatter, this has consequences as regards the meaning of life and on who we are. First up, the in-causal dimension of holomatter vindicates free will, a notion often dismissed as an outdated illusion of folk psychology. Granted, free will is limited, being freedom *under constraint*. Having free will means you can decide to move you head to the right or to the left on whim, but also, far more importantly, to be able to choose life, to choose unconditional love and to choose a healthy lifestyle. It makes resilience and empowerment possible realities in our life, *if we decide so*.

Holomatter also entails that we are not isolated. We are interconnected to virtually everything and everyone, through the countless and unseen[92] bonds of entanglement (or *supralness*) that weave a universe-wide network in which we partake. This implies that "*All lifeforms are part and parcel of a big whole, of a cosmic community held together by a universe-wide patchwork of unseen 'psi'-threads, tangles and webs*." Because of this, we truly belong to something larger than ourselves. We *"bask in an all-encompassing 'psi'-pool that […] can be likened to a world-soul, to an indwelling energy which permeates everything and everyone. […] This pool […] makes us vastly larger than life*[93]." The 'psi'-threads which bind us to the immense world-soul gives us virtually boundless "psychic wings". This resonates with this inspiring image of the Plato: "*Man is a plant, whose roots are up in heaven*" and with this thought of the great American psychologist William James: "*We are all like islands, separate at the surface but connected in the deep*."

We are not separate entities. Like islands, we are interconnected deep underneath the surface of tangible realities. James also wrote: "*We can experience union with something larger than ourselves and in the union find our greatest peace*." This "something" is like a universal and all-pervading memory bank that remains mostly unconscious or subconscious, and is akin to Carl Gustav Jung's

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89 Again from my article 'Panpsychism, Conscious Brain, and Beyond'. The 'psi' field refers to the overall in-causal and psychic dimension of holomatter.

90 Eben Alexander, *Living in a Mindful Universe*, Rodale, 2017. Melvin Morse, in *Where God Lives* (*op. cit.*), writes similarly: "*Can memory exist outside the body? This would seem to be a shocking question, yet no modern scientific or medical theory currently explains memory and where (and how) it is stored. […] There is no coherent theory of how memory works. […] There is a timeless, all-knowing space through which we have access to memory [and] mystical insights*."

91 This citation and the next are from my text entitled 'Expanding Matter: A New Postmaterialist take on Quantum Consciousness', in *Expanding Science*, AAPS Press, Tucson, AZ USA, 2020.

92 Supral links—or bonds of supralness, and hence of quantum entanglement— can't be seen because they are made from the unseen "yolks" or 'psi' parts of particles. This is very fortunate because, were they visible, they would form a thick foggy screen that would blur our eyesight!

93 From 'Panpsychism, Conscious Brain, and Beyond', already quoted.

collective unconscious. Joseph Murphy was aware that "*The subconscious mind has a memory of everything that has ever happened in the history of our species*[94]."

APPENDIX A: Realism with a quantum twist: the way of the snail

Classical realism is based on the common-sense tenet that every object and every piece of information that exist always do so in a clear-cut state and independently of any observer. This is implied by the EPR reality criterion stated in the famous EPR paper published in 1935 by coauthors Einstein, Podolsky and Rosen: "*If, without in any way disturbing a system, we can predict with certainty (i.e., with probability equal to unity) the value of a physical quantity, then there exist an element of physical reality corresponding to this physical quantity*." This realism is *local*, in the sense that it agrees with the principle of locality which states that a physical change somewhere cannot cause or influence a change elsewhere faster than the speed of light. The speed of light in a vacuum is the "speed of causation" because causal influences cannot travel any quicker.

The shift from classical to quantum physics put paid to classical realism. There is no room for it in quantum mechanics, which asserts, in its current interpretation, that a particle is a hazy cloud of probabilities that we don't recognize as real, until it is observed and becomes something definite that we recognize as real. For example, "*Before the speed or position of an electron is measured, […] the electron doesn't have a speed or a position. The measurement brings the property in question into being. […] According to the standard way of thinking, the observation causes the wave function to instantaneously "collapse" back to a single particular value*[95]."

Peter Gribbins explains: "*Quantum mechanics is most easily interpreted anti-realistically, that is, as a theory which, though it works, does not describe the world as it is. […] Realism in the philosophy of quantum mechanics means the idea that quantum systems are really like classical particles.* Everything points against it[96]." In quantum physics, it is unclear whether the particle exists before a measurement is made, which collapses its wave function. It seems that reality at the quantum level is created by the act of measurement. This led John Archibald Wheeler to claim that "*To be is to be measured*", this implying that only sharp states truly exist[97], and Albert Einstein to wonder: "*Does the moon still exist when no one looks at it?*" Niels Bohr, a founding father of quantum mechanics, once quipped: "*Everything we call real is made of things that cannot be regarded as real*."

Locality is another casualty of quantum physics since the collapse of the wave function happens everywhere at the same time and thus violates Einstein's principle of locality. Upon collapsing, a particle "*which is somehow distributed over a large region of space, becomes localized instantaneously, the act of measurement appearing to change the physical state of the system far from the point where the measurement is made. Einstein felt that this kind of action at a distance violated the postulates of special relativity*."[98] Understandably, Albert Einstein was flustered by this "spooky action at a distance": "*Einstein made the point that […] the unequivocal appearance of the particle at one location, is happening simultaneously with the indisputable disappearance of the particle from all other locations. It's a violation of the principle of locality […]. The collapse of the wavefunction, in this way of thinking about it, is instantaneous and patently nonlocal*[99]." Of course, non-locality in quantum physics is also due to entanglement.

Some believe that the collapse, this instant shrinking of the wavefunction, is just a theoretical artefact and not a real event. They think that its very weirdness hints at the fact that the wavefunction itself is nothing but a theoretical artefact, precisely a probability distribution[100]. However, warns Jim Al-Khalili about quantum objects, "*We should not dismiss their existence just because we cannot have a mental picture of what they are really like*." Furthermore, "*All objects, whether microscopic or macroscopic, have many well-*

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[94] From Joseph Murphy, *The Power of your Subconscious Mind*, Pocket Books, 2006. Murphy argues that "*Over ninety percent of your mental life is subconscious. If you fail to make use of this marvelous power, you condemn yourself to live within very narrow limits*." And also: "*Trust your subconscious completely. Know that its tendency is always lifeward*." Some methods, like the controlled remote viewing developed at the Stanford Research Institute by parapsychology researchers Russell Targ and Harold Puthoff, aim to tap this subconscious memory bank. Melvin Morse writes: "*Remote viewing involves mentally tapping into a place that contains the information of the universe, one where past, present and future have no meaning*." (Melvin Morse, *Where God Lives*, *op. cit*.)

[95] Hans Christian von Baeyer, in *Scientific American*, Vol. 308, No 6, June 2013.

[96] Peter Gribbins, *Particles and Paradoxes*, *op. cit*.

[97] This however can't be true, as evidenced by Heisenberg's uncertainty principle, which implies that when we measure the position of an electron, it becomes sharp and well-defined in position… at the cost of becoming fuzzy and ill-defined in momentum (so are the rules of wave interference). *Should we then contend that the measured electron exists and doesn't exist simultaneously, depending on what property we consider?*

[98] Jim Bagott, *The Meaning of Quantum Theory*, Oxford University Press, 1992.

[99] Anil Ananthaswamy, *Through Two Doors at Once*, *op. cit*. To say that a collapsing quantum particle disappears "*from all other locations*" means that it collapses wherever its wavefunction has a nonvasinishing density of presence—which, in the textbook interpretation, becomes a density of *probability* of presence.

[100] My view is that the collapse is weird because it is a ***paralling*** or a *paral phase*, which means that it relates to the fleeting *paral* guise of a particle, being a non-material event driven by its in-causal "yolk", which is then active.

defined properties (i.e quantities that are not in superpositions of more than one value), such as their mass or electric charge. These things are not subject to any uncertainty[101]."

What about wavefunctions? Do they or don't they have any physical existence whatsoever? Anil Ananthaswamy wonders: "*At the heart of [quantum] formalism is the wavefunction. What do we make of it? Does it merely represent our knowledge about the quantum world, making it epistemic? Or is it something real (as potentially evidenced by interaction-free measurements […]), making the wavefunction a key ingredient of reality and part of the ontology of the world? And regardless of whether it's ontological or epistemic, what does one make of the wavefunction's collapse?*[102]" The wavefunction that describes the state of a particle or of an atom is a probability distribution which gives the odds of what outcome a measurement made right away would get. It is very seldom seen as real and is widely held, instead, as a sheer computational tool remote from physical reality[103].

Prior to being measured and so to speak, *some* properties of a particle are fuzzy clouds of possibilities represented by its wavefunction which, as we know, gives the likelihood of obtaining this and that outcome, should the quantum system be measured (each outcome corresponds to a possible sharp state). In short, *the wavefunction tells us what sharp states it may randomly evolve into, should a collapse happen*. Recall that a collapse may happen only if the wavefunction is fuzzy, i.e. is in a fuzzy state with respect to some physical attribute. This raises the question of what the wavefunction means the rest of the time, when no collapse occurs. A common answer is that the quantum system then doesn't exist—just as live or dead cats do exist… but maybe not the fuzzy live-and-dead cat of Schrödinger that no one has ever seen. Physicist Alastair Rae opined: "*We might wonder how we know that a quantum system exists at all in the absence of any measurement. The answer is that we don't. Until we have measured some property of a system it is meaningless to talk about its existence*."

We gather from the above that classical realism is dead and dusted. It was too naïve. Should we then forsake realism, *any* kind of realism? I don't think so. I believe that there is room for a new brand of realism. This ***quantum realism*** would rely on two guiding principles. The first one, unsurprisingly, is nonlocality. The second one says that ***quantum particles and systems are not passive entities but are "shapeshifting entities" that actively react when facing a quantum threat***. They are not mere passive entities but become *active* when necessary. For example, an electron in a fuzzy state of spin will actively shrink to a sharp spin state, driven by its in-causal part, when a quantum threat is built upon the fuzziness of its spin[104]. The electron reacts on cue as it were, like a snail or a turtle which shrinks when it feels threatened, a snail by retracting its jutting eyes and a turtle by withdrawing head and legs into its shell. ***These shrinking events do not warrant any talk that the electron, the snail and the turtle do not exist***. They do exist, *but not as passive entities*. They are *active* entities that, when in jeopardy, pull off their shape-shifting trick as a winning initiative. This is the gist. We could say that electrons, and quantum systems more generally, are 'snail-like' in the way they respond to quantum threats.

Now, if we were to decide arbitrarily that a snail or a turtle is real *solely* when it is retracted or withdrawn, we would then infer that it doesn't exist in its expanded shape, with protruding eyes or with head and legs out of the shell. Realism would be arbitrary lost. This anti-realist stance would be understandable if a snail or a turtle were always found in their contracted state when seen, as it happens with an electron that we can only watch or observe through a measurement yielding a quantum threat yielding a collapse yielding a sharp state[105]. This unmasks the misconception leading us to gainsay the existence of unobserved quantum systems…

To recap, ***quantum realism is turtle or snail realism***. Of course, instead of withdrawing into its shell or retracting its jutting eyes, an electron shrinks to a sharp state. Yet, like the turtle and the snail, it exists just as well, in a fuzzy state, when we aren't watching; and in threat-free environments more generally. Its fuzzy state disappears when we watch because watching or observing, in a quantum context, is not just watching. It is about forcing the electron into a sharp state by means of a quantum threat that will elicit a

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101 These two citations are from the already cited Jim Al-Khalili's book *Quantum. A Guide for the Perplexed*.

102 Anil Ananthaswamy, *op. cit*.

103 See on page 2, footnote number 4, for my comments on this view.

104 A quantum threat is property-specific, which means that it is built on the fuzziness of the threatened object with respect to a specific attribute or property. Here a detector will shift the electron to a sharp and clear-cut state of its spin by menacing to shatter the electron's wavefunction wholeness through its fuzziness in spin. We recall that when wave wholeness—or *quantumhood*—is in jeopardy, a fuzziness-breaking collapse is in order. This is made plain by the potato-and-knife story in the already quoted 'Making Sense of Quantum Randomness' paper.

105 Indeed, such a criterion of existence doesn't work for quantum objects, as I already pointed out, since by Heisenberg's uncertainty relations a precise value of some physical properties goes hand in hand with an ill-defined value of their (non-commuting) incompatible or conjugate properties. Accordingly, the same particle would be simultaneously considered to exist with respect to its well-defined property and not to exist with respect to its ill-defined incompatible property. Franco Selleri, in its article 'Complementarity and/or Quantum Theory' in *Symposium on the Foundations of Modern Physics 1994*, Editions Frontières, explains clearly what underpins the Heisenberg's position-momentum uncertainty relation: "*The position-momentum (Heisenberg's) uncertainty relation can be explained thus: "Precise space localization of a quantum system can be obtained by measuring position with infinite precision ($\Delta x = 0$). Immediately after such a measurement the wave function becomes the [Dirac's delta] d-function $d(x - x_0)$, if x_0 is the obtained value of position, and the particle can be thought to be really in x_0. But a d-function can be written as a superposition of all plane waves with constant weight, and this simply means that absolutely nothing is known about momentum p_x, or, in other words, that $\Delta p_x = \infty$. In this way one loses completely all knowledge concerning p_x available before the position measurement*." Note that this trade-off in precision or definiteness, between x and p_x (p_x being the component of the momentum p corresponding to x, in our tridimensional space), is due to the way wave interference works and shapes the wave packet to be narrower in its spread, either in position or in momentum but never both at the same time.

protective reaction which—you guessed it—is a collapse driven by its in-causal part, or ”yolk”. This brand of realism—i.e., *turtle* or *snail realism*—implicitly acknowledges the in-causal part of quantum objects, which is what turns them into sporadic *active* entities. Consequently by the way, nonlocality doesn't even have to be brought in as a guiding principle, since nonlocality and distance-blindness are inherent in the in-causal dimension and in the *paral* guise of holomatter. They are so with respect to the spacetime of the out-causal dimension and of the *matter* guise of holomatter.

APPENDIX B: The three secrets of the conscious brain

What can holomatter say, as far as the conscious brain is concerned? Has it anything new and worthwhile to tell? To answer, we must focus on the notions of *paralgen* and *suprel*, which derive from these of paral and supralness[106]. What are they, what do they mean, what do they entail? And will it be possible, perhaps thanks to technological breakthroughs, to put them to the test? These questions may inspire future research. For instance, we could seek ways to check whether qualia and our conscious recollections[107] have anything to do with suprels. The nature of our memory engrams, these frozen shards of the mind as it were, is an issue of paramount importance. Unlocking their true nature will speak volumes about that of the mind. If we were to show that our declarative memory is somehow a “supral memory” (with related features such as non-locality and associativity), this would be a compelling argument in favour of the in-causal and non-material nature of the mind[108]. We could also seek some brain ***paralgens***, these being the putative microstructures responsible for the production, in the brain, of the flows of paral that may underlie our ordinary states of consciousness. If so, altering or stopping their functioning, through highly specific drugs or anaesthetics perhaps, should “warp” or diminish brain awareness. Is it possible to figure out what these paralgens are and where they are in the brain? A few promising clues and leads are available, to pin down some paralgens in our central nervous system. I have argued that if these paralgens exist, they are likely to be found near or in some post-synaptic NMDA receptor channels in the neocortex. Indeed, “*attention depends on consciousness. By the same token, consciousness involves very short-term memory (this type of memory, which surrounds or 'frames' our ever-fleeting perceptual moments, is also called the* working memory*). And then [...] what we are conscious of are the results or upshots of neural computations held in the cortex. So [we] have three pointers (*attention, working memory and the processing upshots*) to get on and elaborate from!*[109]”

To cut a long story short, here is one proposal that looks promising:

> [Post-synaptic] receptors (and what goes with them: effectors and channels) make a very compelling target for speculation about paralgenic microsites [*i.e.* paralgens]. [...] Of particular interest is the so-called NMDA receptor found on the dendritic synapses of pyramidal cells. It is excitatory, and has several critical properties suggesting that it may be involved in a wide range of neurophysical and pathological processes. [...] In addition, the NMDA channel is highly nonlinear [and] is a prime candidate to explain the synchronous oscillatory behavior in the cortex. [...] The conclusion I draw is that at least some NMDA channels in the dendritic spine synapses of the large bursty pyramidal cells of the cortical fifth layer[110] do function as paralgens.

What would make these NMDA receptors inviting candidates to play host to some paralgens? (NMDA stands for N-methyl-D-aspartate.) To answer, we need to have at least a rough idea of what a paralgen should be like:

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106 Recall that *supralness* is a “glue” that binds the in-causal parts of particles. As I see it, this supralness, or in-binding, is the root cause of entanglement. Also, *paral* it is the paral guise of holomatter and its particles, gotten as we know when the in-causal “yolks” are active.

107 Our conscious recollections belong to the so-called declarative memory. Neuroscientists know a lot about memory, which is a huge and complex topic that cannot be treated in a few paragraphs.

108 Today, the prevailing theory of the conscious mind rests on the reductionist assumption that mental states are identical with brain states and are mere side-effects of brain chemistry. As for the prevailing theory of memory, it rests on Donald Hebb's postulate of synaptic plasticity: Hebb assumed in 1949 that patterns of synaptic activity may produce a long-lasting strengthening of synapses, whereas inactive synapses will be weakened. Suprels seem poised to offer an alternative. They are based on supralness (or on entanglement) and so are non-local and *invisible* psychic entities. The link I see between them and the (non-local) memory engrams would explain why it seems all but impossible to identify any location of our recollections in the brain. Interestingly, it seems that a possible, but as yet highly speculative, role of entanglement in the brain is now accepted. For instance, we read in *NewScientist* No 3503 (dated 10 August 2024) under the heading ‘Brain cells may communicate using quantum entanglement’: “*Pairs of particles linked by quantum entanglement may be produced by the brain's nerve fibres. This phenomenon could explain how millions of cells synchronise their activity to make the brain function. […] When any two objects are quantum entangled, changes in one [may] immediately cause changes in the other—so if different parts of the brain were entangled, they could synchronise faster than through any other type of connection*.” Supralness, as handled by the biological brain, would enable neurons to fire in synchronized wave patterns within the 35-85 Hz range across several cortical zones spread over the two halves of the brain, notably when the organ of thought is caught in some conscious attentional tasks.

109 All the quoted passages that follow are from my article ‘Panpsychism, the Conscious Brain, and Beyond’, in *Science and the Primacy of Consciousness*, The Noetic Press, Orinda, CA USA (2001). See also my article ‘Peeking at the Conscious Brain: New Clues, New Challenges’, *J. of the Western Chapter of the Alternat. Natural Philos. Assoc. (ANPA)*, **5** (2), 6-26, 1995.

110 This proposal draws part of its inspiration from Francis Crick's 1994 best-seller *The Astonishing Hypothesis*. Note that the cortex has six layers.

> We can think of the paralgen as a sort of biological device—*e.g. an allosteric protein molecule?*—that would be akin to a channel endowed with a snare; into which, say, ions and molecules are sent by the relevant assemblies of neurons [...] whence they undergo a paral phase before being released and 'unparalled' again...
>
> In all likelihood paralgens, in order to *enparal*—*i.e.* to turn into paral—the flows of incoming suprels, must somehow stand in their way. Since suprels are supral patterns that bind together particular clusters of ions, molecules and the like, a fitting and likely locus for paralgens is near, athwart or inside certain synaptic pores and channels. These make perfect spots to enparal waves of successive ions, as they flood through.

I then add, in the same article:

> As for ions, of paramount interest are the calcium ones (Ca^{++}). Calcium is one of the key substances driving nerve signaling. (The NMDA receptor-linked channel, it turns out, is a calcium channel.) It is a ubiquitous intracellular second messenger, [often] released as a wave (Cooper *et al.* 1991), and it plays a role in the 40 hertz oscillations.
>
> On the face of it, I suspect that at least a fair share of these ions, in the relevant pathways and brain areas, partake of the alleged information-laden suprels. (I'll label them, for short, the "sub-suprel" ions.) If so, they would, on simultaneously going through the relevant channels, be collectively *enparalled* and thereby release in the mind the qualia they share.
>
> Another point is that a "paralgenic" channel ought to exhibit a high degree of selectivity. It should emphatically let in the "sub-suprel" ions *only* (or anything close to that), as they reach tidally from the underaware part [of the cognitive iceberg, a conceptual model of perceptual awareness], […] to secure a high signal-to-noise ratio—otherwise the meaningful psychic information would be swamped in a wasteland of background noise.
>
> Indeed, the NMDA receptor channel—both ligand-gated and voltage-dependent—seems pointedly designed to display such a sharp selectivity (Levitan & Kaczmarek 1997)[111]. This is as yet another encouraging feature.
>
> Furthermore, the NMDA system has a well-researched role in mental retardation and in degenerative conditions […] where scientists have observed a "decreased population of the receptor for glutamic acid of the [...] NMDA type" (Ryall 1989). Lastly, anesthesiology appears to bring some extra insight of its own (Flohr 1995, 1996). As we read in (Flohr 1996), "*General anesthetics have a common operative mechanism: they directly or indirectly affect the function of the NMDA system*."

Perhaps a practical way to check whether the NMDA receptor channels (or some other promising ligand-gated channels) plausibly yield some of the brain's *supralled paral*, or ***supparal***[112] for short, would be by means of monitoring the selective impact, on the wakeful mind, of some high affinity molecules (or ligands) specifically geared to them, maybe brought in by some drugs. This could be experimented in animal models at first. Beyond that, the proof of the pudding is in eating it, and the ultimate proof of the relevance of holomatter would come from making artificial paralgens. This would be a huge breakthrough, paving the way for sentience-bearing exo-biological ***supparal***….

To recap, my proposal is that the brain catalyses ordinary consciousness by producing large flows of supparal, a trick made possible by the throngs of paralgens that it would possess in some areas (mostly in its cortex, presumably). It rests on the concepts of paralgens, suprels, and supparal—these being the three secrets of the conscious brain. Suprels would be churned out in highly specialized areas that partake in the massively parallel neural processing in the brain[113]; and the flows of brain supparal would be lavishly suprel-studded to make our rich and vibrant inner life possible. This is what we can tentatively say within the holomatter framework.

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111 *References*: (Levitan & Kaczmarek 1997): Levitan, I.B. & Kaczmarek, L.K., *The Neuron. Cell and Molecular Biology. (2nd edit.)* New York: O. U. P., 1997; (Ryall 1989): Ryall, R.W., *Mechanisms of Drug Action on the Nervous System. (2nd edit.)* Cambridge: C. U. P., 1989; (Flohr 1995): Flohr, H., 'Sensations and Brain Processes', *Behavioural Brain Research*, **71**, 157-161, 1995; (Flohr 1996): Flohr, H., 'An Information Processing Theory of Anaesthesia', *Consciousness Research Abstracts, "Tuscon II"*, 70, 1996. Note that we may expect paralgens, if they exist, to have a stimulatory impact on brain's activity rather than an inhibiting one. The good news, then, is that NMDA channels are 'glutamatergic'; and glutamate is the main stimulatory neurotransmitter in the brain, playing a key role in learning, motivation, memory and neuroplasticity.

112 Recall that ***supparal***—or *supralled paral*, produced when scores of entangled (i.e., *supralled*) webs and networks of holoparticles switch simultaneously to paral—is invisible by its paral side and nonlocal by its supralness side. This would explain why the mind is nowhere to be seen inside the skull and why no well-localized "centre of consciousness" has been found in the brain. (Within the holomatter framework, *supparal* is the underlying material of ordinary sentience and awareness.)

113 For example, visual suprels would be made in several areas of the visual cortex. Of great interest are micro-areas known as cortical columns. Discovered by Vernon B. Mountcastle in 1957, they are columns or cylinders of neurons that work together on a single job. These highly specialised modules of brain computation seem ideally suited to be involved in specific suprel-churning activities (e.g., outputting suprels that encapsulate a given hue of blue colour…). Note that the way the brain handles the supralness side of its *supparal* output—if the holomatter framework is relevant—is still an uncharted territory.